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ABSTRACT

This book is a teacher's guide to energy alternatives. It is divided into seven informational packets on the following topics: parabolic solar concentrators, solar flat plate collectors, wood as fuel, heat loss, bio-gas, wind, and water. Each packet contains background information for the teachers and learning activities for the students. The teacher's section has a bibliography with the usual annotation information. The student activity section includes a detailed description of the activity, usually with illustrations, and a list of the materials, time, and money needed to complete the activity. These activities are designed for secondary school vocational and industrial arts students. (MA)

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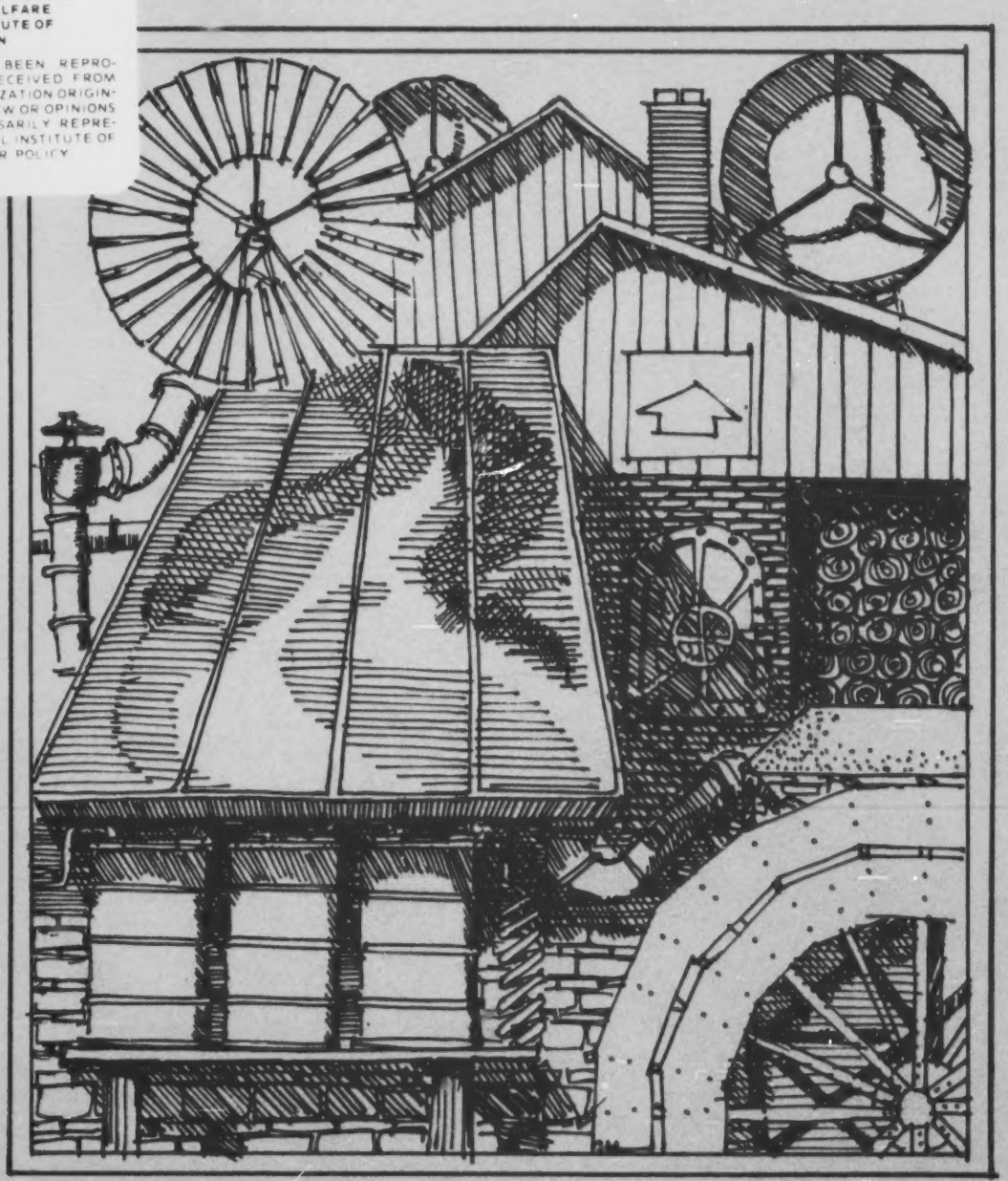

vocational and industrial arts packets

ENVIRONMENTAL ENERGY EDUCATION PROJECT **E.E.E.P.**
MAINE AUDUBON SOCIETY · GILSLAND FARM · OLD RT. 1 · FALMOUTH, MAINE

SE 023370

Credits: Many people were responsible for the completion of this book. However, primary credit goes to the dedicated staff who got this project off the drawing board. Special thanks to researchers Charles Page and Tripp Royce, consultant Charlie Wing, editor Linda Suttenfield, and artists Michael Lewis and David Larson.

Jonathan Gorham
EEEP Director

September 1977
Falmouth, Maine

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INFORMATIONAL PACKETS FOR VOCATIONAL AND INDUSTRIAL ARTS TEACHERS

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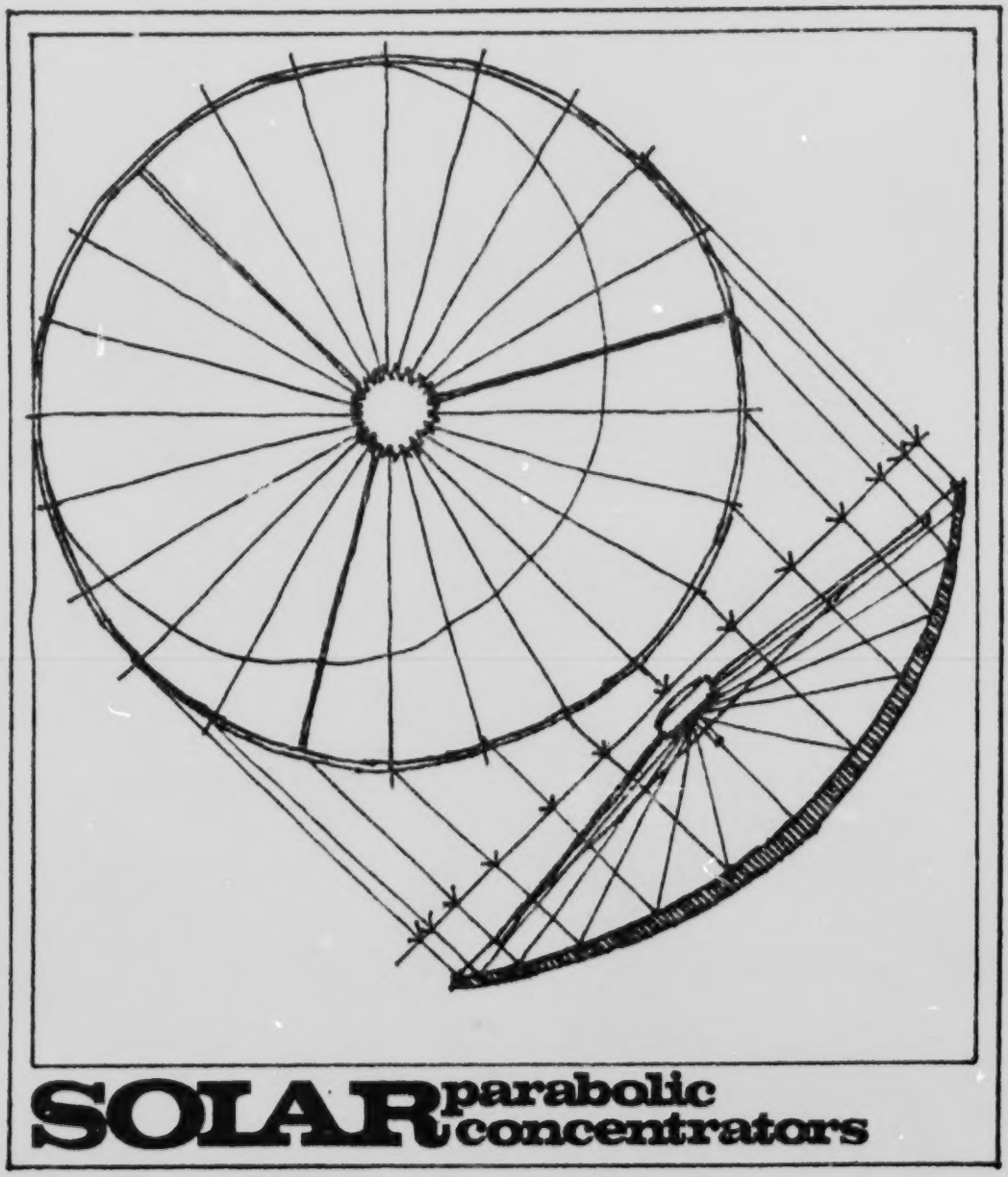


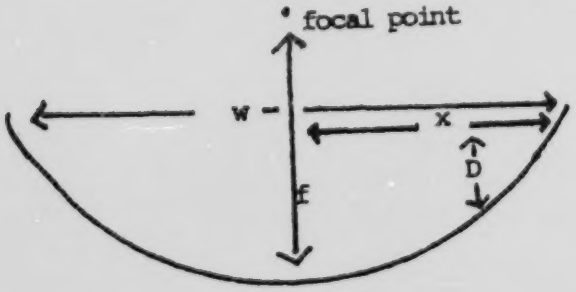
SOLAR parabolic concentrators

TEACHERS GUIDE TO PARABOLIC COLLECTORS

Overview: The general principle that parallel incoming light rays can be reflected and concentrated at a focal point by a concave reflecting surface has been the basis for solar furnaces capable of reaching extremely high temperatures. Would you believe that a 60" diameter spherical parabolic mirror can generate temperatures in excess of 6,000° f? With the expense and impending scarcity of fossil fuels, focusing collecotrs are now being considered for home cooking ovens as well as for the production of domestic hot water.

Obviously the shape of the concave reflecting surface affects the nature of the reflected light. A parabolic surface has three advantages over a circular curved surface. With a larger surface area effectively directing light to a focal point, there is a higher concentration of light per sq. ft. of reflecting material. The parabolic shape requires less supporting material and is therefore cheaper to build and lighter in weight than other concave shapes.

With the help of the following mathematical formula one can design cylindrical and spherical parabolic collectors of various sizes and BTU outputs:



$$D = \frac{1}{16} \cdot \frac{w^2}{f} - \frac{x^2}{4f}$$

w = width of the collector
f = focal length
x = distance from center line of parabo to any point along the curve
D = depth of the parabola at any point

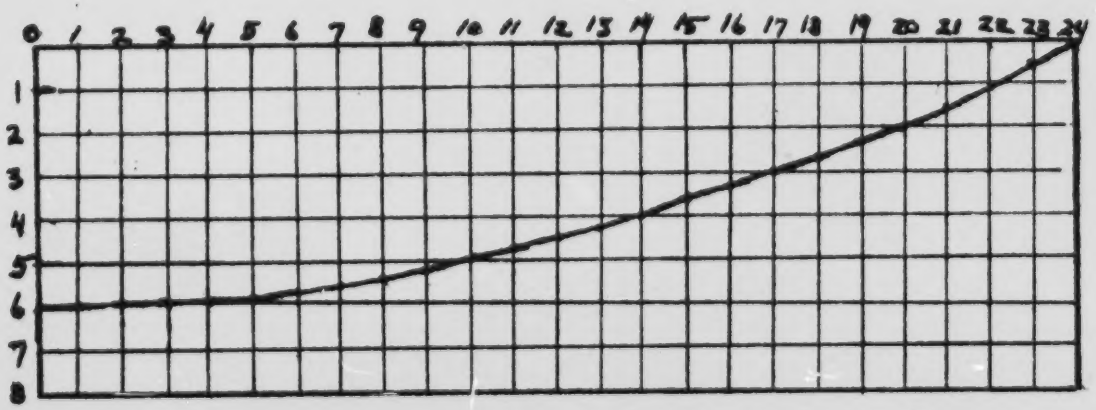
Example: Assume you want to make ribs for a cylindrical parabolic collector utilizing 4' x 8' pieces of plywood. 4' wide ribs would best utilize the plywood and therefore would be a convenient collector diameter. An efficient

focal length is approximately 1/2 the diameter , say 2 feet,. With these two variables known we can use the formula $D = \frac{1}{16} \cdot \frac{w^2}{f} - \frac{x^2}{4f}$. Converting feet to inches and plugging the numbers into the formula we find that

$D = \frac{1}{16} \cdot \frac{48^2}{24} - \frac{x^2}{4(24)}$.

On a piece of posterboard 24" x 8", mark off a grid of 1" squares. (This size is convenient because the template we ant to make is 1/2 the final width of 24" and the depth of the parabola plugging 0 in for x is only 6 " thus leaving 2" for support). Holding the posterboard horizontally, label each line across the top from 1 to 24 and each line along the left hand side from 1 to 8. Subsititute x (0 to 24) and plot D values along the vertical axis. An approximation of 1/2 the parabolic reflector is produced. By connecting the dots and cutting along the resulting line a template can be made for the manufactur of either spherical of cylindrical collectors. See diagram

x	D	x	D	x	D
0	6	9	5.16	17	2.99
1	5.99	10	4.96	18	2.63
2	5.96	11	4.74	19	2.24
3	5.91	12	4.50	20	1.83
4	5.83	13	4.24	21	1.41
5	5.74	14	3.96	22	.96
6	5.62	15	3.66	23	.49
7	5.49	16	3.34	24	0
8	5.34				



The maximum direct radiation falling upon a surface perpendicular to the suns rays at noon on a cloudless day is about 300 BTU/s.f. hr. Since the solar constant (the radiatio at the top of the atmosphere) is about 430 BTU/s.f. hr., a minimum of 30% of the direct radiation is intercepted by the atmosphere.

The theoretical power generated by the collector can be calculated from the formula:

$$\text{Power} = I \pi R^2$$

Where I = intensify of direct radiation, 300 BTU/hrs.f.

R = radius of collector in ft.

Thus the collector of radius 2 ft. theoretically should produce 3770 BTU/hr. or 1100 Watt Due to the reflectivity of the foil (about 0.65) and the difficulty in achieving a perfec parabolic surface, one might reasonably expect about 500 Watts to be delivered to the food being cooked. The maximum temperature achievable is easily 200°C - close to the flash point of paper and wood - so the collector must be stored out of direct sunlight when not being used.

Design Considerations: It has been mentioned that a focal length equal to one half the diameter of the collector gives good efficiency. Long focal lengths like this have to be adjusted more often to track the sun than do those with shorter focal lengths. Shorter focal lengths, on the other hand, are more difficult to make because of their steeper sides.

Both spherical and cylindrical collectors have their limitations, Spherical collectors produce high temperatures because the light can be concentrated from a rather large area to a simgle point. Heat losses at that point can therefore be decreased. Cylindrical collectors produce much lower temperatures. They distribute the heat over a linear focal point (called a focal axis). Ease of construction makes this form applicable to low temperature domestic hot water production.

A cloudy day makes a parabolic collector inoperable, because diffuse radiation, that sunlight scattered by water and dust particles as the sun's rays travel through the earths atmosphere can not be utilized. Likewise, if the sun's direct rays approach the collector at an angle to the center line, the focus of the rays will miss the target located at the focal point. Tracking the sun during the course of the day is a difficul problem. All sorts of mechanical and electrical devices have been designed to solve thi problem. The simplest and most widely used method for small collectors is manual adjustment.

The efficiency of a collector has a great deal to do with the reflectivity of the collectors surface. The following is a list of reflective materials that have been used successfully to make low cost parabolic collectors:

Material	Where To Find It	Cost
Aluminum foil	Grocery Store	1.2¢ sq. ft.
Aluminum Roof Flashing	Building Supply	.10¢ sq. ft.
Builders Foil	Building Supply	1.5¢ sq. ft.
Aluminum Sheet	Plumbing & Heating Supply	.62¢ sq. ft.
Aluminized Mylar	Kalwall Corporation Manchester, N. H.	.14¢ sq. ft. p.]
Bathroom Mirror Tile	Building Supply	
Old Army Search Lights	Army Surplus Catalogue	

Just about any reflecting surface that can be bent into a parabolic shape will work.

The framework for parabolic collectors have been made from a variety of materials. The cardboard ribs used in Activity #2 could easily be replaced by plywood or metal ribs just as the flashing in project #3 could be replaced by foil covered fiberglass sheeting Plastic foams, fiberglass and even cement have been used for supporting the reflective surface. It is important to realize that most of the materials can be obtained cheaply by scrounging and recycling older materials.

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Energybook #1: Theoretical explanation of parabolic, spherical and other concave reflective surfaces. Contains plans for a parabolic reflector made from sheet aluminum. Shows schematic of cylindrical parabolic kitchen stove, also information on flat plate collectors, solar heated housing and windpower. Contains photo illustrations and bibliography.

2. Halacy, Jr., D.S., Solar Science Projects, Scholastic Book Services, New York, 1959. $. 75

Solar Science Projects: Easy to follow explanations on how to make the following; a reflector cooker, solar still, solar furnace using a fresnal lens, solar oven, solar hot water heater, solar motors and sun powered radio. Illustrations, photos and bibliography included.

3. Hankins, William H. and Wilson, David, Practical Sun Power, Lorien House, P.O. Box 1112, Black Mountain, N.C. 28711, 1974. $4.00

Practical Sun Power: Excellent Book showing the "how tos" of making spherical and two cylindrical parabolic collectors, a sheet metal solar oven, an inexpensive solar hot water heater, a solar room heater which would attach to most windows, small solar furnace using a fresnal lens and a solar still. Illustrations, photos, and bibliography included.

4. Daniels, Farrington, Direct Use of the Sun's Energy, Ballantine Books, 201 E. 50th St., N.Y., N.Y., 1974. $1.95

Direct Use of The Sun's Energy: Theoretical as well as practical explanations on all aspects of solar energy. It has detailed explanation of parabolic collectors and explains how to build one using fiberglass. Contains illustrations, photos, and extensive bibliography.

STUDENT ACTIVITIES

ACTIVITIES	MATERIALS	COST	TIME	PLANS & SUPPLEMENTRAY INFORMATION
#1 Concave Reflective Surfaces	See project enclosed	aluminum foil .012¢ per sq. ft.	2 hrs.	
#2 Parabolic Cardboard Cooker	See project enclosed	$10.00	24 hrs.	1. pp. 103-106 2. pp. 14-27 3. pp. 4-12 4. pp. 43-72
#3 Cylindrical Parabolic Reflector & Hot Dog Cooker	Aluminum flashing, plywood, strapping	$10.00	10 hrs.	3. pp. 6-8
#4 Parabolic Spherical Reflector	aluminum flashing, plywood	$15.00	20 hrs.	3. pp 8-11
#5 Ring Parabola Reflector using mirrors	plywood, 4" x 4" mirrors	$12.00	5hrs	1. pp 105-106 substitute mirrors for sheet aluminum plans also available from S. Pitney, 150 Sandwich St. Plymouth, Mass 02630
#6 Ring Paraboloid Reflector	foil covered plywood, aluminum sheet	$10.00	5 hrs.	1.ppp 105-106
#7 Solar Cigarette Lighter	see project enclosed	$2.00	7 hrs.	

Concave Reflective Surfaces

or

How To Make Junk Work For You

Just about everyone at one time or another has used a magnifying glass to burn h's or her initials into a piece of wood. As light passes through the glass it is bent to a concentrated point we call the focal point. There is another way to focus light which doesn't require the expense of buying a glass or a plastic lens. Concave reflective surfaces will reflect light to a focal point. The reason this happens is because light bounces off a reflective surface at the same angle as it arrives. When light strikes a curved surface at an angle perpendicular to the front of the concave shape it is reflected towards a central point - the point where all the reflected rays come together is the focal point of that concave surface.

In this exercise you will be experimenting with various concave reflective surfaces to see how this principle works.

Materials	Cost
1 roll of aluminum foil	$2.35

The rest of the materials you have to scrounge. Look at home, around the school or perhaps at your local dump to find five objects that have smooth inner concave surfaces. Here are a few examples of the type of things to look for: An old umbrella, baby moon hub caps, kitchen collander, the lids to cooking pots, a top cover to a ringer washing machine, snow sliding saucers, wash basins, and mixing bowls.

Proceedure: Line the inside with aluminum foil making sure that the shiny side is facing outward. This might mean glueing the foil to the concave surfaces or possibly attaching it with clear plastic adhesive tape.

A. Take the five reflectors outside on a clear sunny day.

1. Direct the reflectors one at a time into the sun. This can be done by supporting one edge on the ground while someone holds the back at the correct angle.
   a. Feel the foil lining. Does it get hot?
   b. Hold a pencil so that it sticks out from the front of the reflector, casting a shadow on the foil. Is there any heat generated? Do you notice a focal point? How did you find it?
2. Move the reflectors slowly away from the sun. What happens? Experiment to see where the best possible angle is to catch the maximum amount of sun. How do you know when the collector

is catching the most sun? How would this angle change in the course of a day?

3. Are there some shapes that work better than others? Could you actually cook with the best one you have found?
4. Dampen a paper towel and hang it at the focal area of the best reflector. Does the paper dry faster than one placed beside the reflector?
5. List three possible uses these reflectors that you have made might have. List 10 uses that concave reflectors might have in the U.S..

B. Cut a window in a number 10 can and line the inside with foil.

1. Direct it into the sun. Is there a focal point? Where is it? How might this focal area be used?
2. Rotate the can reflector on its long axis. Does the focal point move?
3. Suggest three uses for this type of reflector.

C. Obtain a piece of shiny sheet aluminum approximately 2' x 3'. (File off any burrs so that you won't get cut.) Face the sheet into the sun with the 2' side up. Rest the bottom on the ground and have one person bend the sheet into a curved concave form.

1. Is there a focal point? Bend the sheet slowly into a cylindrical shape. How does the focal point change?
2. Holding the metal bent in a concave shape, tilt it toward and then away from the sun. How does this effect the focal point?
3. Turn the bent form away from the sun at various angles. What happens to the focal point?

Student Activity #2

Cardboard Cooker
or
How to Put the Sun to Work Cheaply

When parallel incoming light rays strike a reflective parabolic shape at an angle perpendicular to the reflector's face, the rays are reflected and focused at a point. We call this point the focal point and it varies with the shape of the parabola. A narrow steep sided parabola could have a very short focal length while a flat and shallow reflector would have a long focal point. Much like a magnifying glass, the focused rays generate heat. The larger the collector, the more heat can be generated. In this project you will be constructing a 4' diameter spherical parabolic collector which will generate enough heat to cook a number of things when the sun is shining. The materials are easy to find and inexpensive. With a reasonable amount of effort you will be able to construct this cardboard cooker without any difficulty.

Materials:		Cost:
Cardboard	(1(48" x 48" approx. 40 sq. ft. (16) 24" x 9"	free
Posterboard	(9) 22" x 28"	$3.60
Aluminum foil	16 sq. ft.	.50
Air plane glue	(2) 4oz. tubes	$2.30
Elmers glue	as required	$2.25/pt.
Masking tape	1 roll	$1.60/60 yd.
Grill	approx. 8" x 8"	
String	1 ft.	
Bolt with 2 washers and wing nut 1/4" x 2		.50

2 Pg 2

Materials Cont:		Cost:
Strapping	(2) 2' x 3/4" x 4'	.30
	(1) 2' x 3/4 x 3'	.11
Weight		free
Dowel	1 ft.	

Tools:

Pencil, string, razor knife, scissors, tack, sabre saw, drill, tape measure, framing square.

Procedure:

The 48" x 48" piece of cardboard serves as the foundation for the ribs. If this size cardboard is hard to obtain a number of smaller pieces of cardboard may be glued together or plywood or composite board may be used. It is important that the surface be flat. Lines dividing the square into four equal parts will locate the center and allow you to scribe a 48" diameter circle. Cut along the circumference with a razor knife and draw lines outward from thecenter dividing each quarter into 4 equal parts. (Approx. every 22.5') These lines mark where the 16 ribs are to be glued.

The base for our demonstration model was made from 9 medium sized cardboard boxes glued in three layers. A liberal amount of Elmers glue was spread between each layer of flattened boxes. Placing the layers at right angles to one another increased the laminate's strength. Cement blocks placed on the cardboard kept the glued surfaces together while they were drying. The ribs were made from 4 boxes 12" wide and 12" high. By opening the bottoms of the boxes and flattening the sides together, each piece consisting of a top, a side, and a bottom was 24" long - just the right length for the ribs[Cardboard braces 5" wide and 8" long were glued over the two creases on each of these sections to make them rigid. We

We used a framing square and razor knife to square off one long side and an adjoining short side. These edges must be straight as they are to be glued to the base and serve as the framework for the posterboard on the circumference of the reflector.

Tape a 9" x 24" piece of cardboard to a flat surface in front of you. Draw a line 1 3/4" high all the way across the bottom of a straight long side. Starting from the lower right hand corner, follow the right hand edge of the cardboard out 20" and mark this point with a tack or brad. Place a framing square with its body against the tack and pivot it around, a few degrees at a time, keeping the heel of the square on the horizontal line which you have drawn, and marking the tongues edge with each movement. The lines will form a parabolic shape which can be used as a template for the other fifteen ribs. (See Diagram) Cut along the edge of the lines, and trace around this template for the shape of the other ribs.

Glue the ribs onto the baselines using air plane glue. It will be neccessary on some of the ribs to trim between 1/2 and 1" off of the narrow end to insure the proper fit. Don't worry if not all the ribs are touching in the center though, what is important is that they are flush with the outside of the circular base. To hold each rib upright while it is drying stretch masking tape, like the guy lines on a tent, from the parabolic edge to the base on both sides. When the rib is firmly cemented remove the tape and use again for another rib.

Set the finished cardboard framework on blocks so that the posterboard can easily be glued to the circumference. Cut a 22" x 28" piece of posterboard into three 9 1/3" x 20 1/4" sections. Apply airplane glue to the outside edge of three ribs and base and press posterboard section to this glued section. Stapling the posterboard to the cardboard framework

this glued section. Stapling the posterboard to the cardboard framework using a heavy duty staple gun helps hold the posterboard in place while the glue drys. Don't worry if the posterboard extends below the bottom of the base or beyond the edges of the ribs on the circumference. Having the top edge of the posterboard line up with the upper edge of the ribs is more important. When the posterboard is firmly in place turn the collector over and trim off the excess posterboard extending below the base and apply masking tape to this edge.

Fashion one of the interior facing pieces from the posterboard using a razor knife or scissors so that the edges of this piece extend over the ribs by 1/8". This is to allow for any variation in the spacing between ribs. Using this as a template cut 15 other cover pieces.

Fit and glue cover pieces to the ribs in alternate spaces. Press and hold the ribs together until the airplane glue is able to set. By trimming the narrow end of each piece by 1" or 2" you avoid messy overlaps in the center section. The second course should be laid over and glued to the first. Taping the joints here and there will allow you to go on to the next cover piece without waiting for the glue to harden. A circular piece of posterboard, glued over the center will cover up the uncovered center sections. Trim and tape posterboard along circumference to neaten reflectors appearance.

Cut aluminum foil, with scissors, into sections that closely resemble those sections in the completed covering. Do this carefully as wrinkles in the foil will decrease the efficiency of the reflector somewhat. Keeping the shiney side outward, glue the 16 foil pieces with airplane glue or rubber cement to the inner covering. Do not use Elmers glue for this as it will cause the covering to warp.

Drill a 3/8" hole in both the front and back, at the reflectors center point, and insert and glue the 3/8" dowel. This dowel will indicate whether the reflector is lined up with the sun properly. The sun is shining directly into the reflector when the dowel casts no shadow.

A 4' x 2" x 3/4" piece of strapping, sharpened at one end, so that it can be hammered into the ground, and with nails stuck into the narrow edges at 2" intervals serves as the reflectors vertical adjustment system. When the collector needs to be repositioned a string, which is taped to the base near the bottom rim of the reflector, is simply retied in a new location. (see fig. A)

The grill stand is made with the two remaining pieces of strapping. Sharpen the 3' piece on one end and cut a 3/8" wide, 1' long slot, 2' up from the sharpened end. (see diagram E) Approximately 29 1/2" from one end of the smaller piece drill a 1/4" hole and make notches along the remaining 18 1/2" every 2" to accommodate a hanging counter balancing weight for the pots and pans set on the grill. Bolt the two pieces together with the 2" x 1/4" wing nut, bolt, and washers. Fasten the grill to the horizontal bar with string or wire.

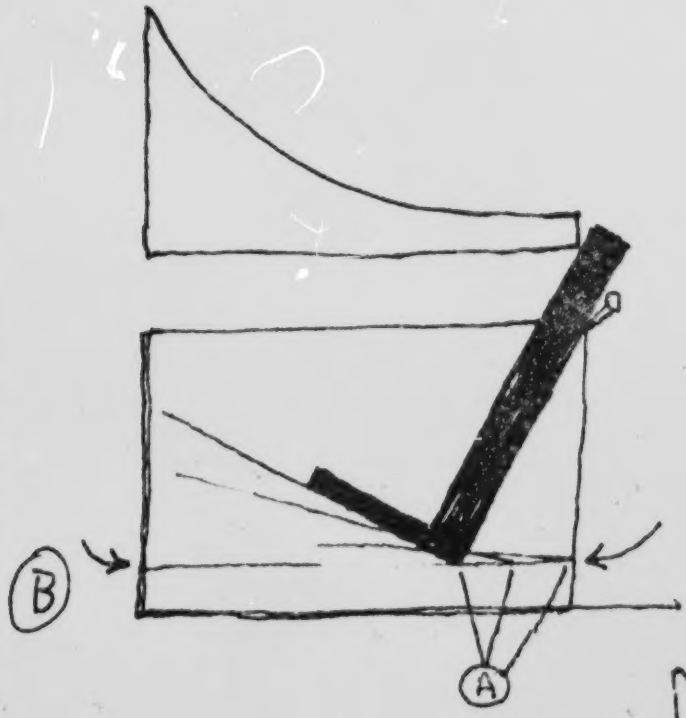
Cooking with the sun is carefree... there are no fires to kin dle, and no expensive stoves or fuel to buy...yet you must be aware of the natural laws that make your solar cooker possible . Repositioning the reflector every so often to recieve the suns direct rays and moving the grill to and away from the focal point to recieve different amounts of heat, are things you will have to experiment with to perfect your cooking techniques. Remember that dark pans will absorb more heat than shiney ones and that a grease covered reflector surface will produce less heat

than a clean shiney one. One note of caution is in order here. Faced into the sun the reflector is extremely bright. We recommend wearing a welding mask while you are looking into the reflector. Sun glasses just won't do!

When you are sufficiently skilled in the art of using your cardboard cooker cook a meal for a skeptic... it may be the cheapest meal they ever ate!

Can you answer these questions?

1. What might be some of the ways of keeping the parabola in line with the sun?
2. What practical applications can you see for this type of collector besides cooking food?
3. What other materials might be used to construct such a collector? What other types of materials would make it longer lasting and more durable? Can you suggest a way to make a portable folding collector? Can you design a better mounting system for the grill? Outline the steps one would have to go through to make one.
4. What are the advantages and disadvantages to this type of collector?
5. What other factors besides smoothness of surface (reflectivity) affect the rate of cooking? List ways to increase the efficiency of the cooker you have built.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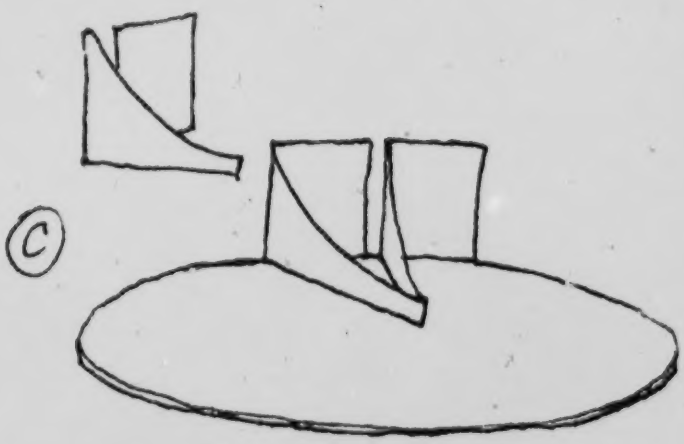
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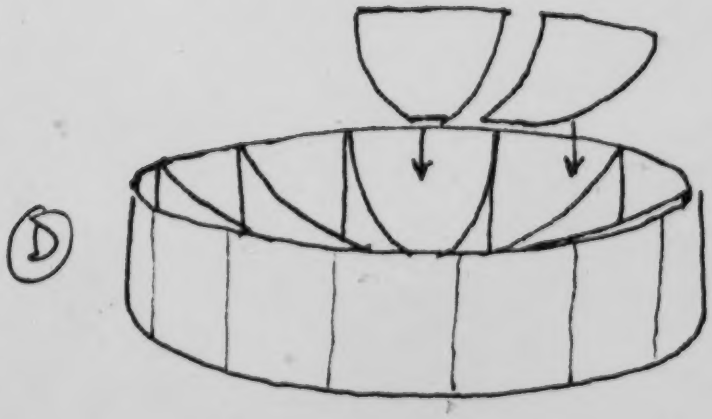
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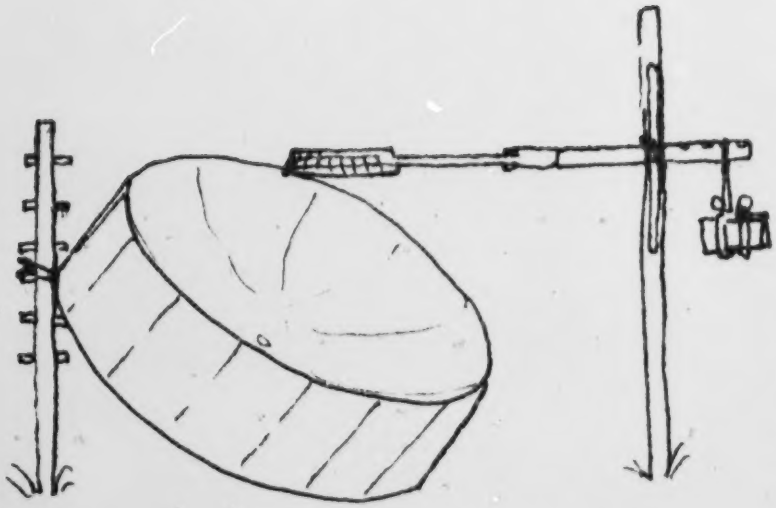

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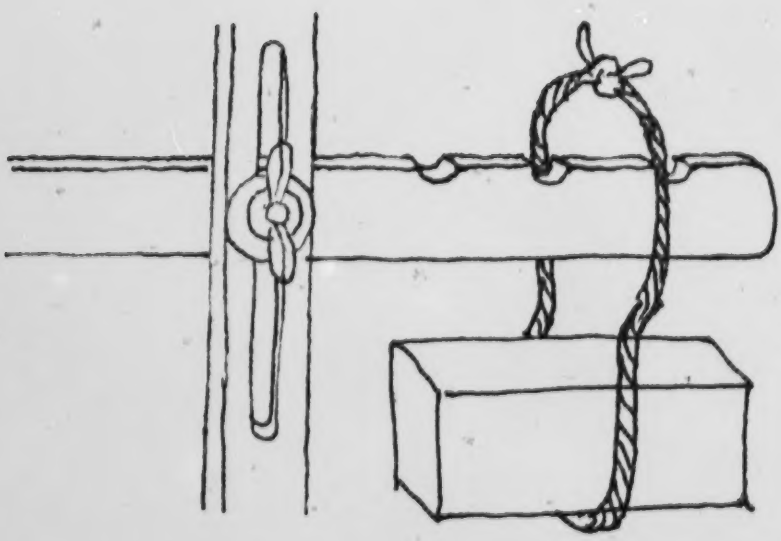


Activity # 7

Solar Cigarette Lighter

You are standing in a group of friends. Your buddy's cigaretter bobs, Bogart style, as he searches pocket to pocket for the matches that aren't there. Fighting off a smile that later explodes into a laugh, you loosely slide a solar cigarette lighter from your back pocket. Five seconds later his cigarette is lit. No flick of your Bic. With the sun it's quick.

This may sound far fetched, but there are two companies that currently sell solar cigarette lighters; Edmond Scientific Co., 150 Edscorp Building, Barrington, N.J. 08007, and Solar Usage Now, Box 306, Bascom, Ohio 44809.

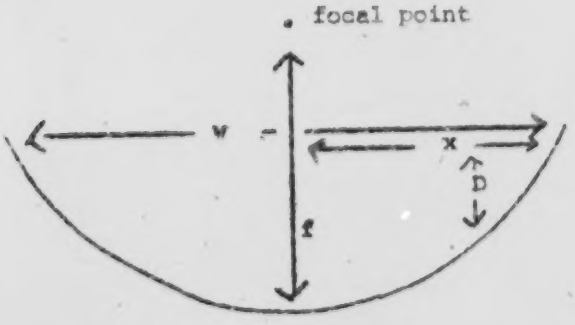
A parabolic mirror approximately 4 1/2" in diameter will generate enough heat at its focal point to light a cigarette in 3 to 5 seconds on a sunny dya. The shape of the parabolic reflector is determined by the relationship between focal point and diameter. A steep sided mirror would have a short focal length while a shallow one would have a long focal length. A focal length of 1/2 the reflector's diameter has proved to be efficient. Both the length and diameter can be altered somewhat without affecting performance. Let your needs dictate its size.

We chose a focal length of two inches so that the depth of our lighter is about 5/8 " - a size that would easily fit into a back pocket. A focal length of 1" on this type of collector would make a reflector 1/2" deep - a size uncomfortably thick for a portable lighter.

Using any one of the following three methods you can determine the parabolic shape of the reflector mirror for any given focal length and diameter.

METHOD # 1

The following mathematical formula shows the relationship between the width of the collector (w), its focal length (f), the horizontal distance from the center line of the parabola to the outside edge at any given point (x), and the depth of the parabola (D).



$$D = \frac{1}{16} \cdot \frac{w^2}{f} - \frac{x^2}{4f}$$

By making the appropriate substitutions we can plot D as a function of x since we have determined values for w and f. The parabolic curve can then be plotted on graph paper.

The pocket of most jeans measures about 5 1/2" x 5 1/2". A 4 1/2" diameter lighter would easily slip in and out of this pocket.

Example: For a focal length pick 2" or roughly 1/2 the diameter. This focal length/diameter ratio is efficient. With these two variables known the formula becomes a handy tool. To make things simpler divide each inch into 10 equal parts so that the reflector is 45 1/10ths of an inch in diameter and has a focal length of 20 1/10ths of an inch. On 1/10th inch graph paper mark off -25 to +25 on the x axis. By plugging in the x values into the formula you will be able to compute the depth at each point x along the number line. Connect the points to form the parabolic shape.

Example: $D = 1/16 \ \ w^2 /f - x^2 /4f$

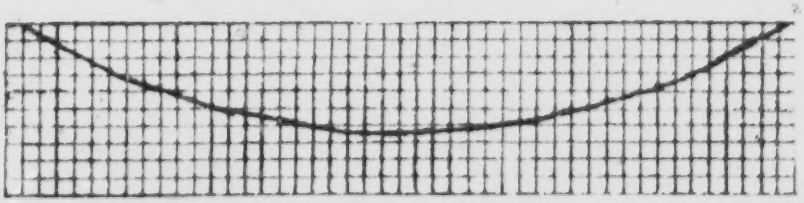
$D = 1/16 \ (45)^2 /20 - x^2 /4(20)$

w= 4.5" = 45 x 1/10 "
f= 2.0" = 20 x 1/10 "

The formula generates the following data;

x	D	x	D
0	6.33	12	4.53
1	6.32	13	4.22
2	6.29	14	3.88
3	6.22	15	3.52
4	6.13	16	3.13
5	6.02	17	2.72
6	5.88	18	2.28
7	5.72	19	1.82
8	5.53	20	1.33
9	5.32	21	0.82
10	5.08	22	0.28
11	4.82	22.5	0.00

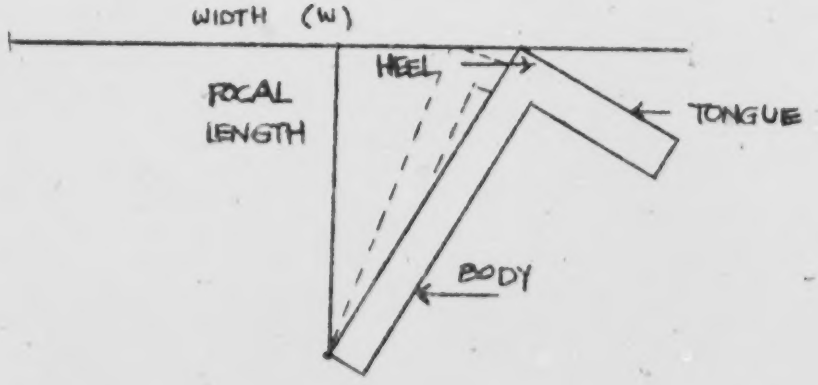
The following parabolic curve is generated when f = 2.0" and w = 4.5"



METHOD 2

The parabolic shape can be determined using a T-square once the focal length and the diameter are known. (see method 1) Place an 8 1/2" X 11" piece of paper in front of you with the long side as the bottom. Draw a line across the paper 2" from the top edge. Mark the center of this line. Place the short side of the square (the tongue) against this line at the center point so that the square's long side (the body) divides the paper in half. Draw a line against the body of the square that extends down from the center point the distance of the focal length.

Making sure to keep the body of the square against the focal length point and the heel of the square on the horizontal line, move the square a few degrees at a time. Mark along the tongue edge of the square after each movement. Continue marknig the lines untilyou have reached a distance of 4" from the center line. Then flip the square over and repeat this process on the other side. When you are done hold the paper at arms lenght and admire the simplicity of the parabolic shape.



METHOD 3

The third method is the most fun. It uses a mira, a 3" X 5" piece of plexiglass mounted between two wooden blocks which keep it upright. Plexiglass is transparent, yet it will project a mirror image to a point behind the plexiglass. This is a great tool for making parabolic shapes.

Draw a line on a piece of paper as long as the width of your reflector. Mark the center point of this line. (w) On the perpendicular bisector of this line place a mark at 2f,the distance of 2 times the focal length from the center point. This construction is made because the mira, when positioned halfway between the point at the end of the focal lenght and the line (w) projects a mirror image of the line on the point. To draw the parabola position one end of the mira at the intersection of the two lines, and locate the reflective surface so that the image of the line intersects the point. (If the point were marked at the focal length the parabola you would draw would have a focal length 1/2 the distance you want.)

Move the mira a few degrees at a time, keeping the image of the line intersecting the point. Mark the mira's edge each time you move it. With this tool it is easy to experiment with various size focal lengths. Miras can be purchased from Ray Fischer at Mt. Ararat High School in Topsham, Maine for $1.00.

TEMPLATE CONSTRUCTION

Materials:

6" X 6" aluminum sheet
6" X 6" X 2" block of hardwood, preferably maple or birch.
2 aluminum rivets

Tools: Lathe, small soft mallet, drill, coping saw with metal cutting blade

Procedure:

Mount the 6"x6" hardwood block on the lathe as if you were going to make a bowl. Carve out a concave parabolic shape using the paper template you have just made as a guide to check the depth of the concave sides. This will be a sherical shape--all sides must curve the same. Sand the concave shape carefully. Remove from the lathe.

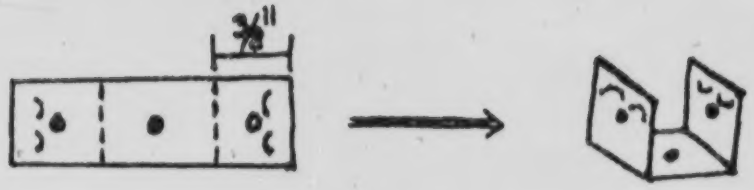
Tack the 6"x 6" sheet of aluminum onto the face of the block. Hammer the aluminum into the form with the mallet. Reattach the block to the lathe with the aluminum sheet in place. Polish the parabolic surface using silicone car wax. This wax will oxidize the surface, allowing it to be shined using borax and water. Buff the surface with a silicone dish towel. There are various polishing agents that can also be used. Remove from the lathe and cut away excess metal from the finished concave mirror, leaving 1/8" on the circumference for added strength.

The mount for the cigarette holder is made from a 1" x 1/4" strip of aluminum. Mark a line 3/8" from each end. Drill a 1/8" hole in the center of each 3/8" section and one in the center of the strip. This center hole will attach the mount to the reflector surface. With a metal punch make two indentations side by side on the outside of the two end holes. These indentations will be used to keep the cigarette holder up-right. Bend the two ends inward at right angles on the 3/8" lines so that the punched in areas face inward. Drill a hole in the center of the mirror. Rivet the mount to the collector surface. See diagrams.

Working from the diagrams, construct the cigarette holder. The holder is made from an aluminum strip aproximately 5/8" wide, cut using the coping saw. The total distance from the surface of the reflector to the end of the cigarette must be equal to the focal length you have chosen. Remember to subtract the finished height of the holder mount (3/8") from the length of the holder you are fashioning. Slide the tabs of the holder into the mount. Your cigarette lighter is now ready to use.

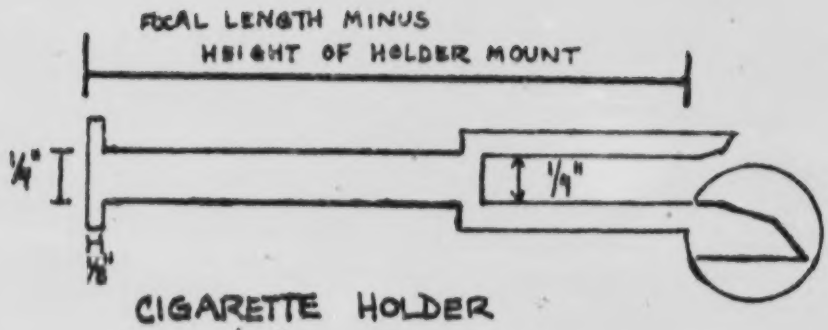
There are a number of other materials that could be used for construction of a similar cigarette lighter. Plexiglass, fiberglass, various plastic resins, wood or metal could be used for structural support. Aluminized mylar, 5 mil chrome metalized film, or aluminum foil could be used as reflective surfaces. We hope that you will experiment with these materials and let us know how they work out.

Materials	Source	Cost
Aluminized mylar	Kalwall Corp., 1111 Candia Rd., Manchester, NH 03105	$ .14 square foot
5 mil chrome metalized film	Solar Usage Now Box 306 Bascom, Ohio 44909	$1.50 square foot

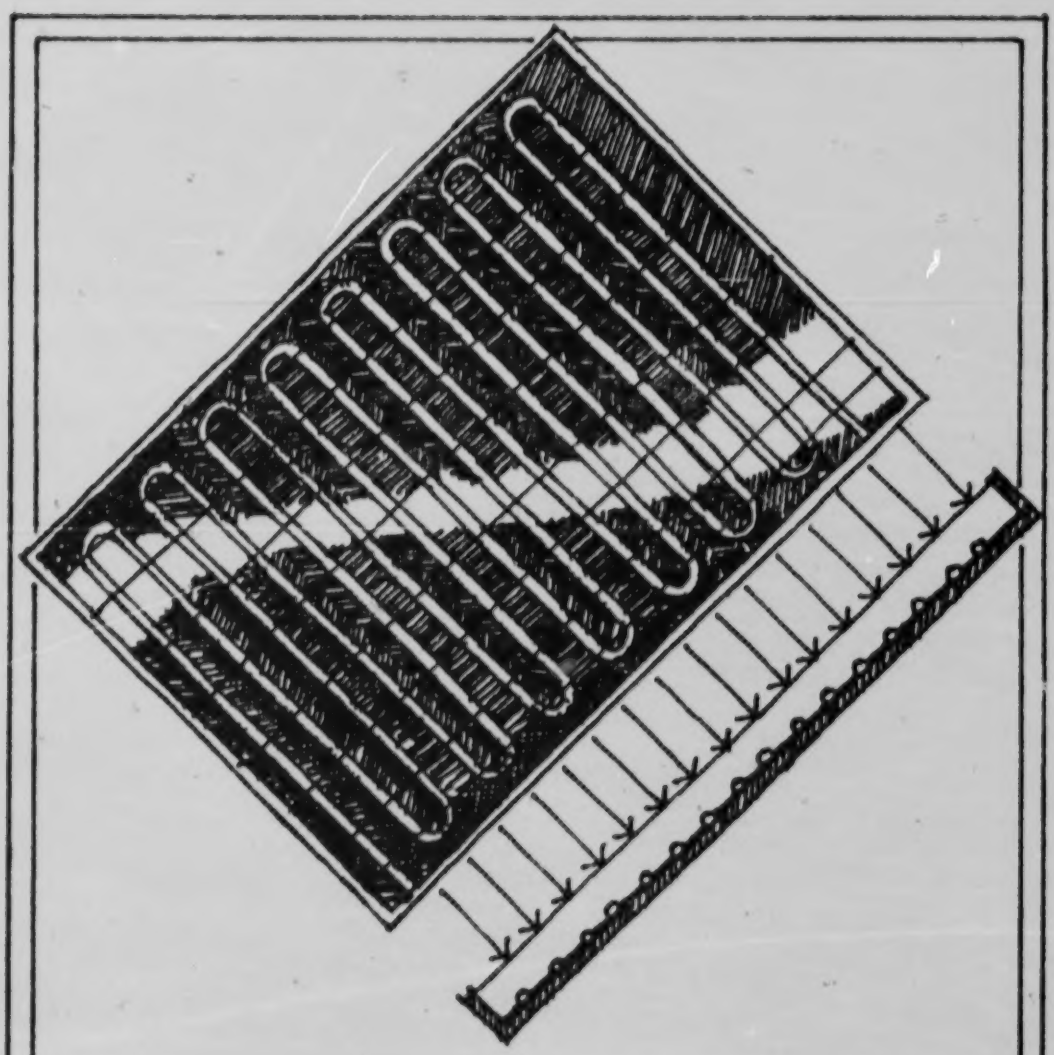


Top View

Front View



CIGARETTE HOLDER



SOLAR flat-plate collectors

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FLAT PLATE COLLECTORS

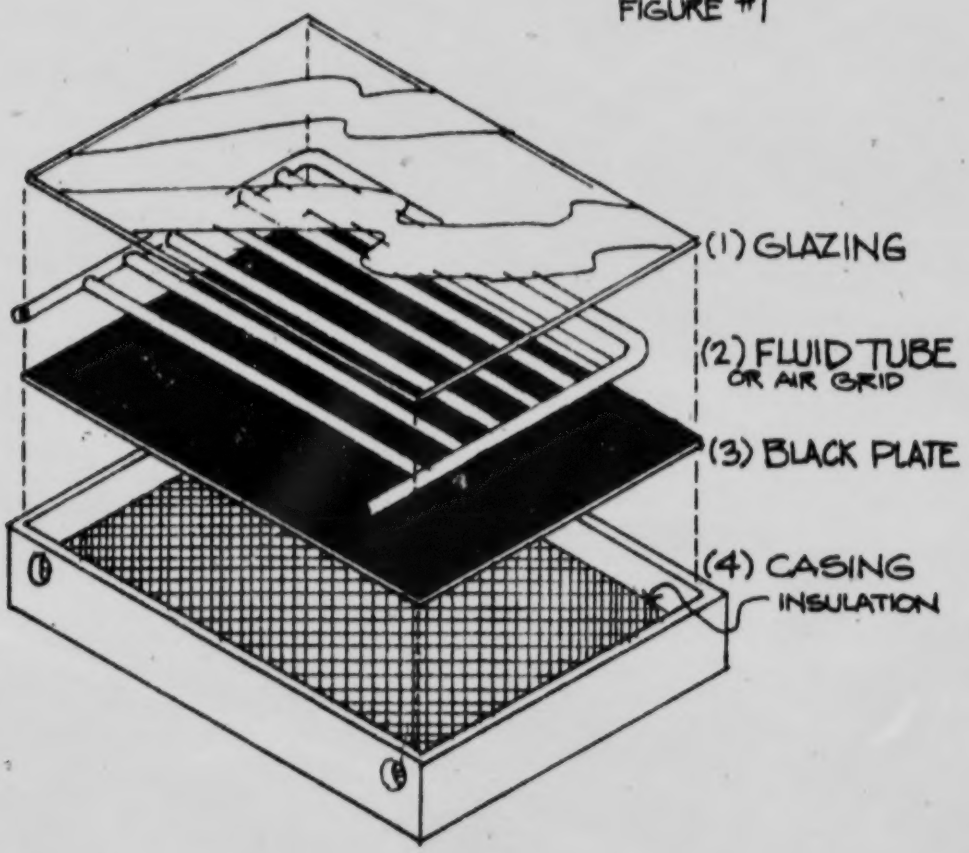
The oil embargo....do you remember the long lines at the gas pumps and the fear in peoples' minds that they would freeze in their homes without oil? Energy planners hoped that the oil embargo would make all Americans aware that we must conserve petroleum whenever possible and that we must look for new ways to generate heat for our homes and our hot water needs. Flat plate solar collectors can provide a partial solution to this energy crisis. It should be noted that flat plate collectors are not new. In the United States during the 1930s there were as many as 60,000 solar domestic hot water systems in operation in Florida. At the present time there are two manufacturers of flat plate collectors in Maine and a growing number of solar heated homes.

The objective of this packet is to provide for teachers a description of the general theory of flat plate collector performance, an annotated bibliography, a list showing cost and source of materials, and a list of student activities. The activities range from simple low cost demonstrations of solar collector theory to units which could actually be used for space heating and hot water production.

Solar radiation, consisting of visible light (47%), infrared or longwave radiation (46%), and ultraviolet or short wave radiation (7%) must pass through nearly fifty (50) miles of atmosphere before striking the earth. On the average of the estimated 429 BTU/ft^2/hr. that enters the atmosphere only 275 BTU/ft^2/hr. actually reaches the earth. The radiation lost is absorbed by ozone, water, oxygen molecules and dust particles. Radiation is also scattered by nitrogen and oxygen molecules. Striking an object on earth, the visible light energy consisting of both direct radiation and scattered or diffuse radiation is converted to heat. Flat plate collectors are designed to capture this heat.

There are four major parts to a collector panel: (1) A glazing, consisting of a substance which will allow light to pass through, yet prevent the reradiated long wave heat radiation from escaping, (2) A fluid tube or air duct grid mounted at least 1" below the glazing which captures and transports the heat to either the living space or a storage area, (3) A black flat plate which will absorb the radiation and conduct or convect it to the transporting medium (air or water), and (4) A casing which shields, protects and insulates the components from the outside weather. See Figure 1.

FIGURE #1



There are two major types of flat plate collectors: air and water. Figure 3 (below) shows cross sections for five liquid and two air type collectors. In collectors A and B, liquid flows through the tubing under normal house plumbing pressure of 20 to 40 psi and is circulated by natural convection or by a small water pump to a storage tank.

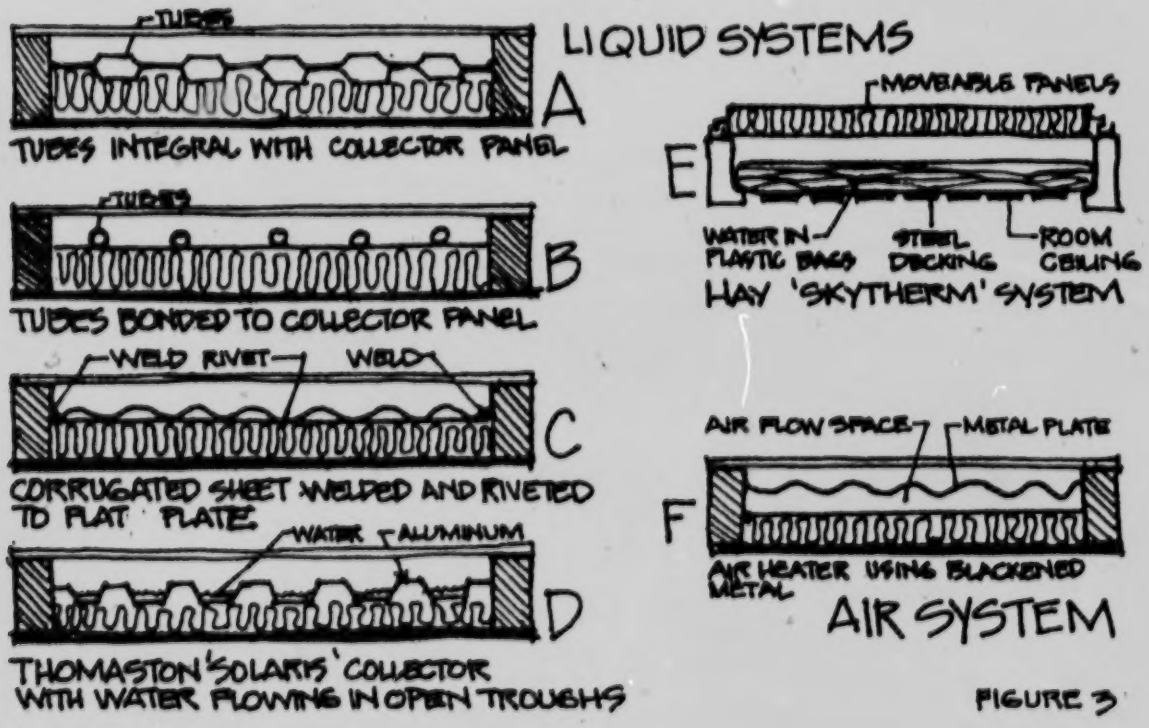


FIGURE 3

Figures 4 and 5 show solar hot water systems. Figure 4 is a pumped hot water system utilizing a small water pump to deliver water to a storage tank. Figure 5 shows a natural convection system known as a thermosyphon system. The fluid can be either antifreeze or water depending on the climate.

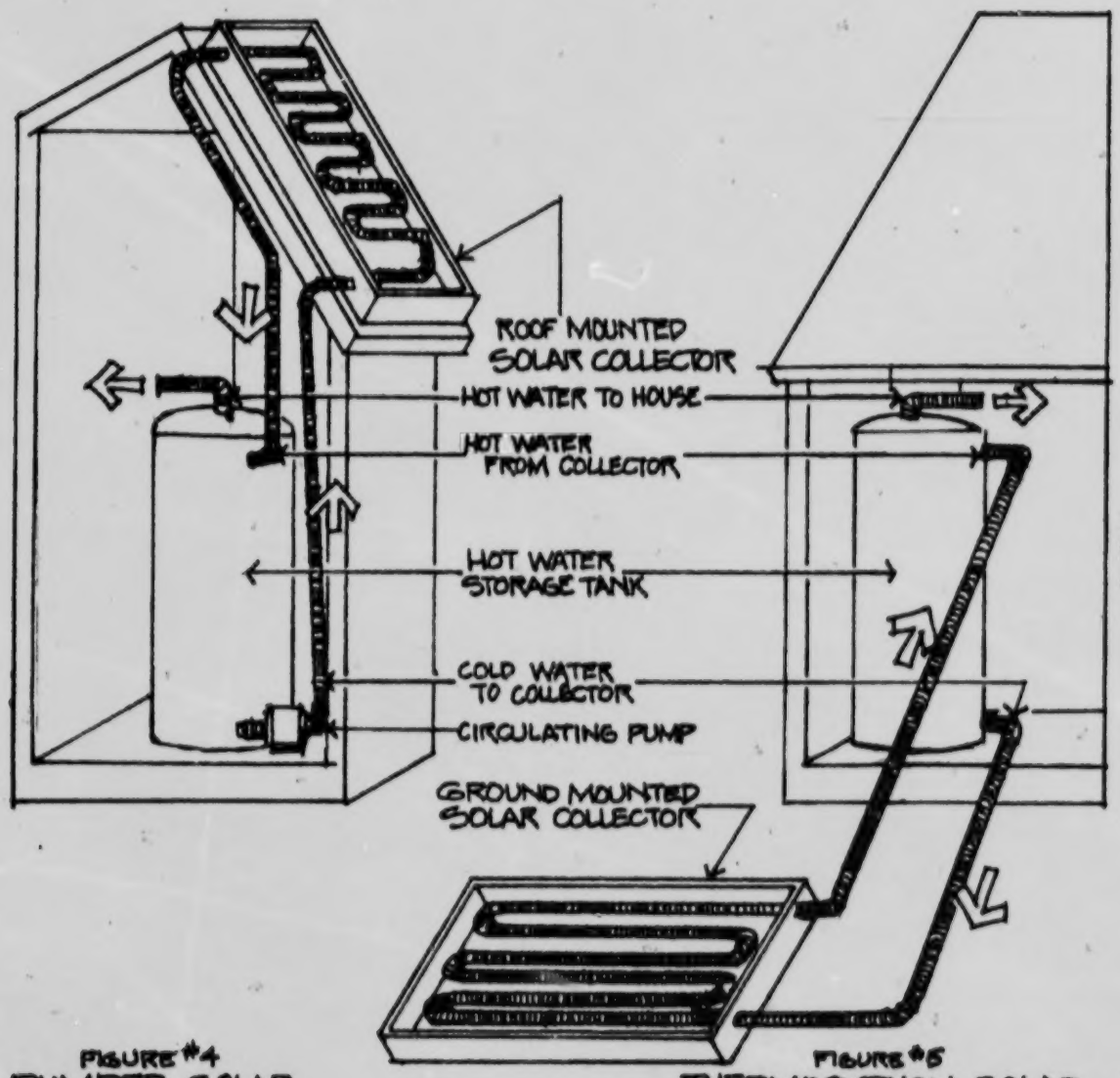


FIGURE #4
PUMPED SOLAR HOT WATER SYSTEM

FIGURE #5
THERMOSYPHON SOLAR HOT WATER SYSTEM

As illustrated on Page 3, collectors C and D are liquid collectors which work at atmospheric pressure. These systems are referred to as trickle systems because the collector fluid is trickled over a black absorber panel and piped into a heat exchanger that transfers the heat to the regular plumbing system or forced air heating system. In collector E the collector and storage system are combined. The insulating panel is removed during the day so that the water in the plastic bags can be heated. At night the insulating panel is closed allowing heat to radiate into the room. This simple system can also be used to cool the room during the summer months by reversing the daylight modes. Panel F is an air type collector. Air passing through the panel transports the heat to a high density material, such as crushed rock, located near the collector. In some collector systems the heated air is circulated directly into the house. The 2,000 square foot air collector used on the south side of the Maine Audubon building in Falmouth is an air type collector. Air is sucked through plywood passageways filled with folded loops of black insect screening (See Figures 7 and 8). The screening absorbs radiation and air passing over it convects the heat from the screen into an 840 cubic foot rock storage. Air systems are used primarily for space heating while water systems are used for both space heating and domestic hot water.

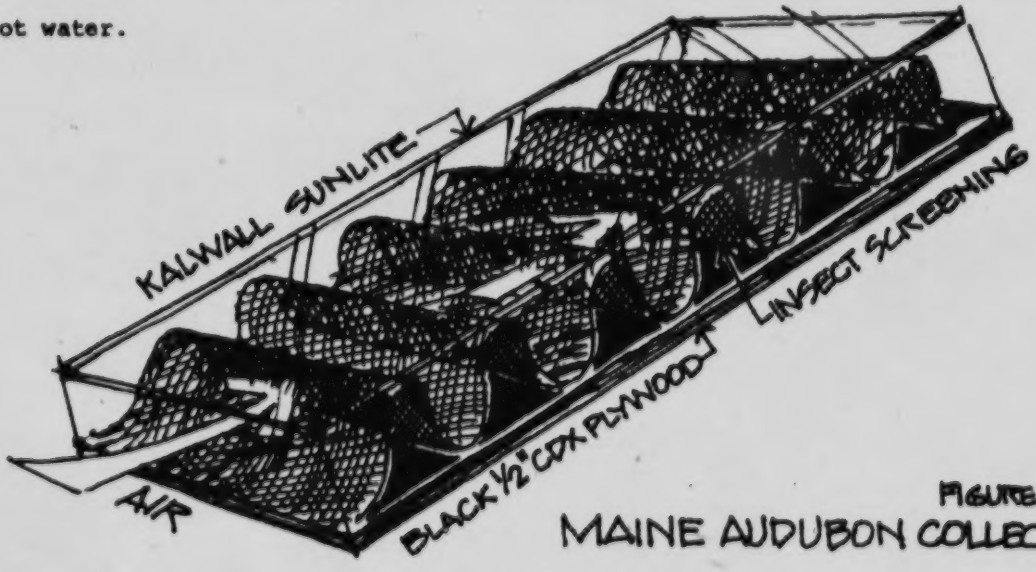
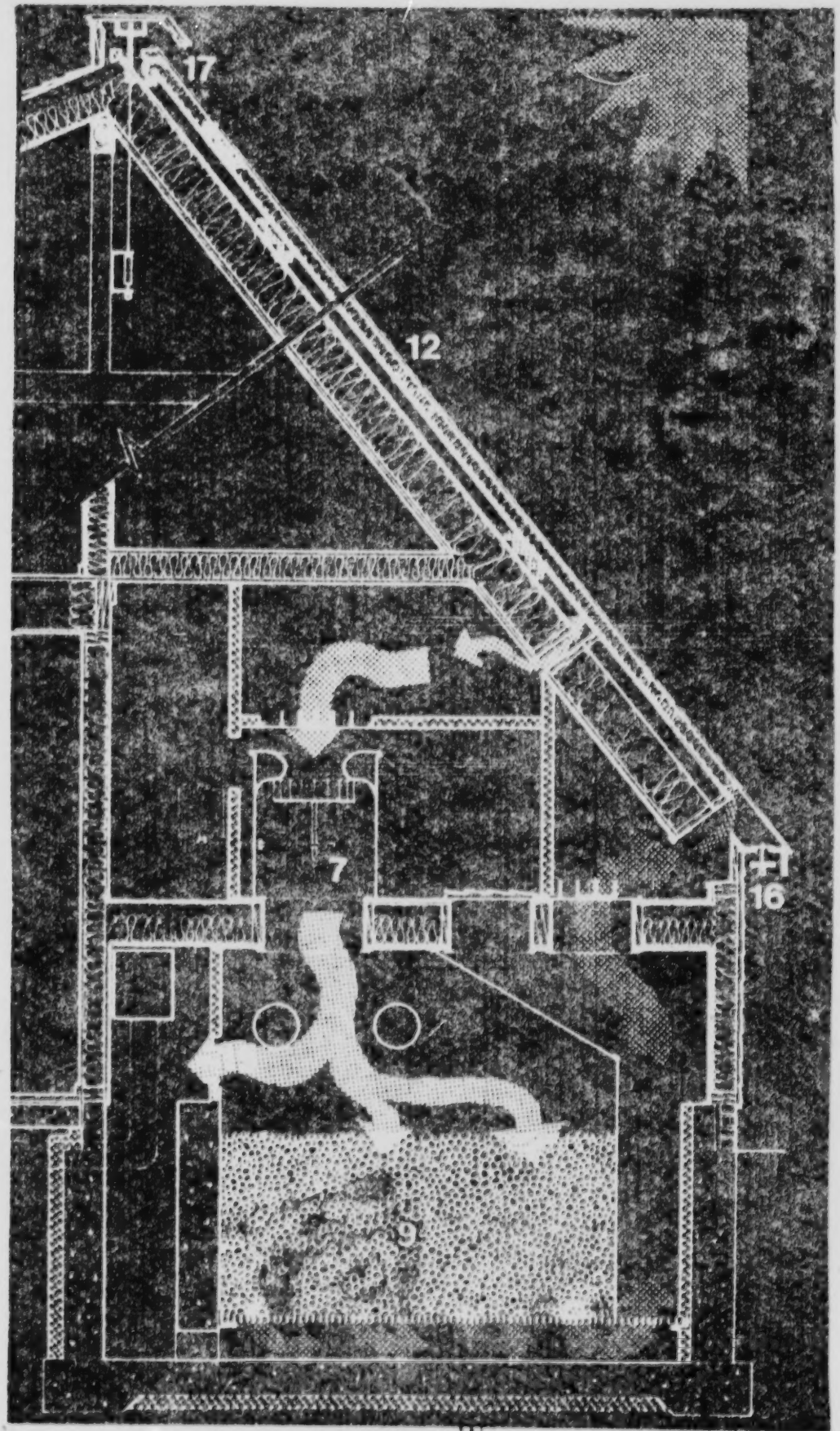


FIGURE 7
MAINE AUDUBON COLLECTOR

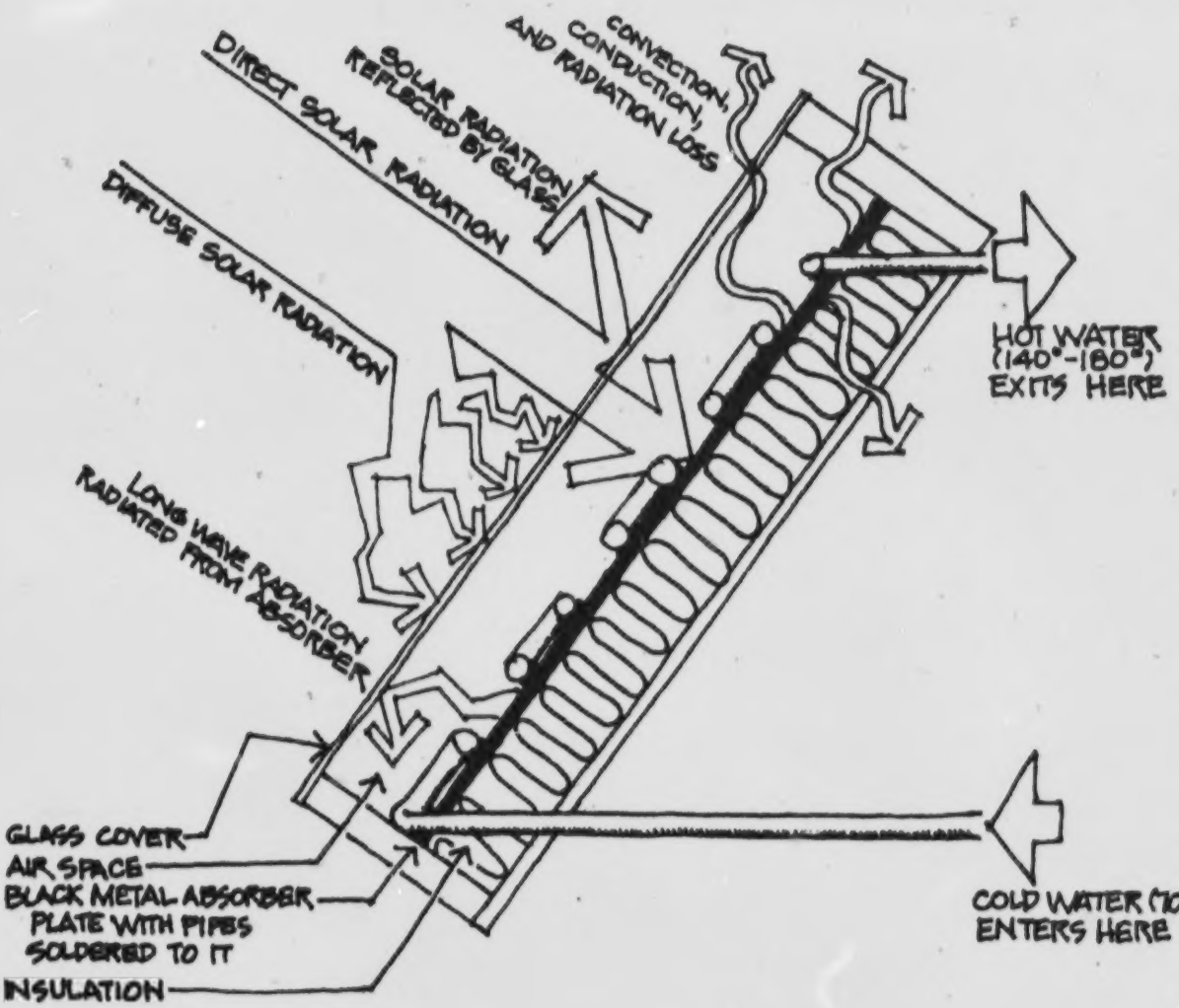
Figure 8



A flat plate collector uses three heat transfer mechanisms; conduction, convection, and radiation. Radiation, simply stated, is the emission of energy in the form of electromagnetic radiation by a warm surface. When a piece of steel is heated red hot some of its radiated energy extends into the visible region. The electrons in the metal, excited by the applied energy, move to a greater distance from the atomic nucleus to a higher energy state. Later this energy is released in t form of radiation as the electrons seek a lower more stable energy state. Conduction is the transfer of kinetic energy from one atom to the next in a substance by the vibration of atoms and electrons. As you know, a substance in which energy readily flows is called a conductor while a substance opaque to the flow of energy is called an insulator. Convection is the transfer of heat from one place to another by the actual motion of the hot material. Natural convection occurs due to density differenc in the fluid while in forced convection the fluid is moved by a blower or a pump.

It is helpful when designing a collector to think about energy transfer in terms of these three transfer mechanisms. Following the energy pathway we find that solar energy is lost when light is reflected or absorbed by the collector glazing and reradiated back into space. (See Figure 9 - Page 8). If the glazing material is glass 10% of the incoming light energy is lost to reflection and absorption.Of the remainin 90% that strikes the absorber surface a certain percentage (depending on the color and texture of the surface) is reflected to the sides and back toward the glazing. The radiation that is absorbed is either reradiated in the form of long wave radiation or back toward the glass or in the case of water collectors is conducted through the fla plate to the transfer fluid. Some of the reradiated heat from the absorber plate is lost through the sides and glazing. In a water type collector it is best to minimize air convection and reradiation from the flat plate and maximize air convection and ab plate reradiation. Air flat plate collectors don't require an absorbing material that has a high conductivity as the reradiated heat is removed by convection rather than conduction.

Figure 9

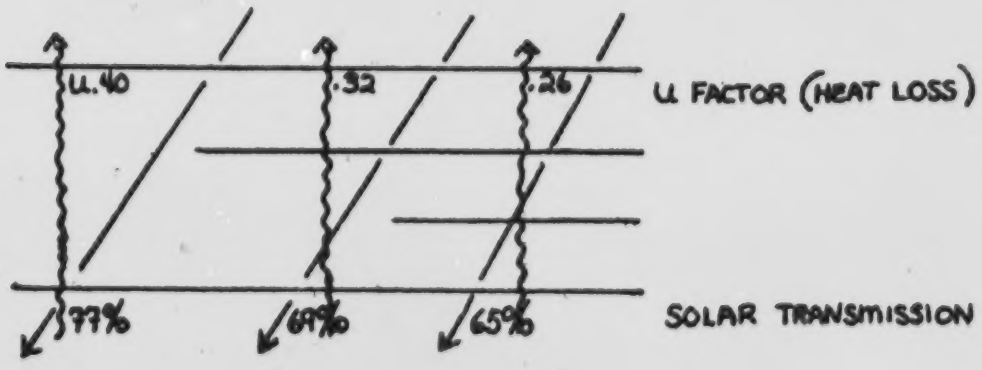

CONVECTION, CONDUCTION, AND RADIATION LOSS
SOLAR RADIATION REFLECTED BY GLASS
DIRECT SOLAR RADIATION
DIFFUSE SOLAR RADIATION
HOT WATER (140°-180°) EXITS HERE
LONG WAVE RADIATION RADIATED FROM ABSORBER
GLASS COVER
AIR SPACE
BLACK METAL ABSORBER PLATE WITH PIPES SOLDERED TO IT
INSULATION
COLD WATER (70°) ENTERS HERE

Some glazings work better than others. Glass is one of the better glazings. It transmits 90% of the incoming light yet, fairly effectively blocks reradiated infrar heat. There is one drawback that makes it an impractical glazing material for Maine high schools .....it is fragile. Plastics have been used successfully for collector glazings. There are disadvantages to plastics also. Most plastics transmit infrared energy. Some become soft at the 200°F plus temperatures found in most collectors. Som have a tendency to rip in the wind and some have short lifespans when exposed to ultra violet light. Teflon, a fluocarbon film, will last 20 years and withstand much higher temperatures than most plastics. A high density plastic produced by Kalwall Corporatic

called Sunlite will take temperatures up to 300°F with only slight changes in solar transmittance and block infrared radiation almost as well as glass. Kalwall is probably the best material for experimenting with collector design as it is rigid and durable and can easily be used over and over again. Many collector manufacturers are using a combination of glazing materials. For example, they might use glass for the first glazing and teflon for the second glazing. The following list of materials includes cost, lifespan in sunlight, and availability.

NAME	MATERIAL	COST	LIFESPAN IN SUNLIGHT	WHERE TO BUY IT
Teflon	fluorocarbon film	15¢/sq. ft. 1 mil thickness	20 years	Dupont Corp. 20 Evergreen Pl. East Orange, N.J.
Tedlar	polyvinyl fluoride		5 years	"
Mylar	polyester		3 years	"
Polyethylene		1¢/sq. ft. 4 mil thickness	½ year	building supply co.
Plexiglass	acrylic		20+ years	building supply co.

A first tendency in building a collector is to use many layers of glazing without taking into consideration how much light is reflected or absorbed by each layer. The following diagram shows the relationship between the u factor (heat loss) and the solar transmission of Kalwall's Sunlite.



Cost must also be considered. The air collector used for the Maine Audubon building is a compromise between cost and efficiency. It was more cost effective (cheaper and lower maintenance) to have a less efficient collector with more area than a highly efficient smaller and more complicated system. Figure 10 shows the relationship between the number of glazings, collector efficiencies, and collector temperature. You will see that at an absorber temperature of 150°F, the

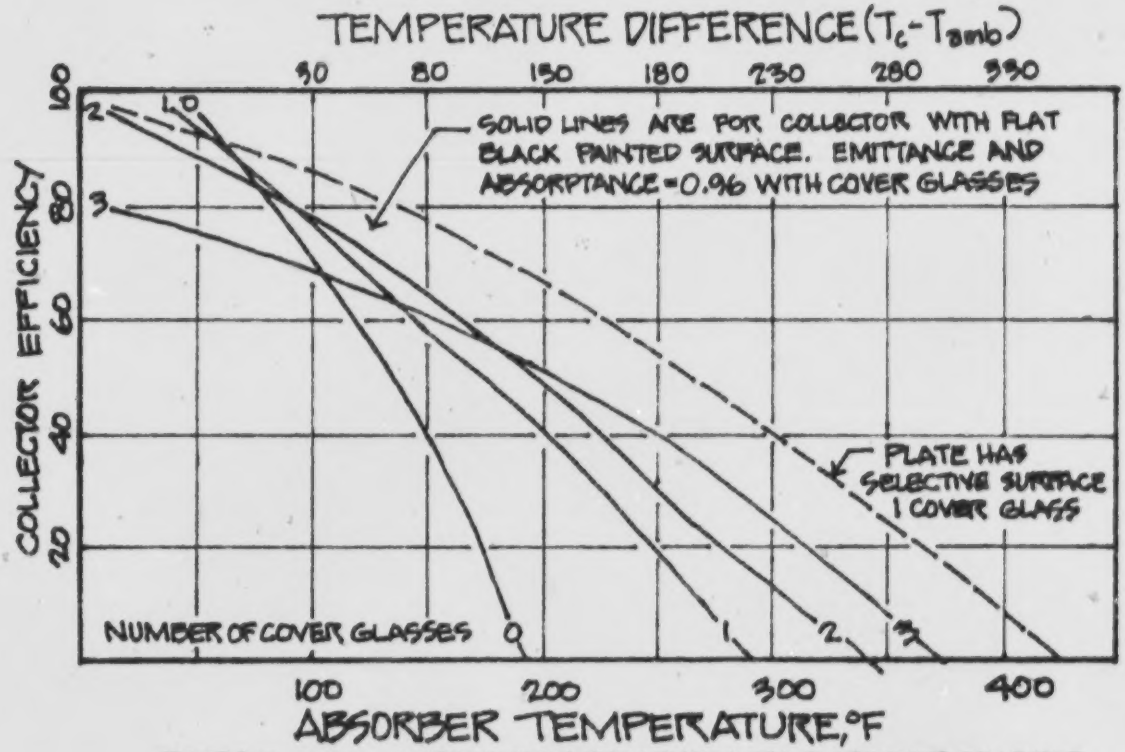


FIGURE 10. TYPICAL INSTANTANEOUS EFFICIENCIES OF A PLATE PLATE COLLECTOR BASED ON TOP OUTSIDE (AMBIENT) TEMPERATURE. USE TOP SCALE TO ESTIMATE EFFICIENCIES AT OTHER TEMPERATURES. NORMAL INSOLATION OF 300BTU/FT²/HR

collector efficiency for two layers of glazing is about 5% greater than for one. A third layer at this temperature reduces the efficiency to that of one layer. At higher temperatures, extra layers do increase efficiency, but heat losses from the collector box are liable to offset this gain.

A criterion for a water-type flat plate absorber is that it capture and transfer the energy absorbed to the circulating fluid. In order to capture the

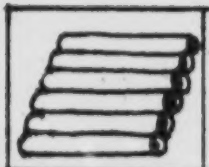
heat, the collection surface should absorb more energy than it reradiates. 3M Corporation markets a "Nextel" brand velvet optical black paint which some manufacturers use as a flat plate covering. (Available from Solar Usage Now, Box 306, Bascom, Ohio) The cost of $45.00 per gallon makes flat black muffler paint look mighty good for most purposes. There are selective surfaces which have been developed using an electroplating process, which reradiate far less radiation than they absorb. Though expensive, a good selective coating would have an absorbtivity/emissivity ratio of .90/.12 = 7.7. Comparing this to a black cupric oxide on a copper surface from Table 2, we find that the selective surface is 8 times more effective as an absorber surface.

EMISSIVITY AND ABSORPTION OF MATERIALS

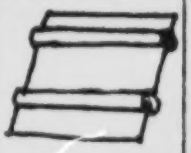
		Emissivity	Absorptivity
1.	BLACK, NON-METALLIC SURFACES	.90 - .98	.85 - .98
	Asbestos (slate)	.96	.81
	Black gloss paint	.90	.90
	Green paint	.95	---
	Black cupric oxide on copper	.96	.91
11.	BRICK & TILE, CONCRETE & STONE, RUSTY STEEL & IRON, DARK PAINTS	.85 - .95	.65 - .80
	Vegetable and shrub fields	.90 (approx.)	.72 - .76
	Red Brick	.92	.55
	Concrete	.88	.60
111.	WHITE OR LIGHT CREAM TILE PAINT, OR PAPER, PAINT, WHITEWASH	.85 - .95	.30 - .50
	Snow	.89	.33
	Whitewash on galvinized iron	.90	.22
	Aluminim oil base paint	.90	.45
1V.	BRIGHT ALUMINUM PAINT, GILT OR BRONZE PAINT	.40 - .60	.30 - .50
V.	DULL COPPER, GALVINIZED STEEL		
	Oxidized Copper	.60	---
	Oxidized Steel	.70	---
V1.	POLISHED COPPER		
	Copper	.15	---
V11.	HIGHLY POLISHED ALUMINUM, TIN, CHROME	.02 - .04	.10 - .40

In transferring the heat once captured, it is advantageous for the absorber material to have a low specific heat and a high conductivity. Specific heat is the amount of heat required to raise the temperature of a unit quantity of material 1° F. The greater the specific heat, the more heat the material can hold for a given change in temperature. Let me give you an example of how this would affect the efficiency of a collector. Assume a 3' x 6', 300 lb. steel collector plate is directed toward the sun. By multiplying the weight of the storage mass (300 lbs) by the specific heat of steel (.11), we can determine the amount of heat stored in the collector per degree rise in temperature. We find it takes 33 BTU of heat energy to raise the collector temperature 1 F.°. This means that 4950 BTU would be needed just to get the temperature up to an efficient operating temperature of 150° F. On a partly cloudy day when there is about 100 BTU/sq. ft./hr. of light energy striking the collector surface, there is only 1800 BTU/hr. being generated. If a steel collector weighing only 60 lbs. of the same dimensions were used, only 990 BTU/hr. would be needed to reach 150° F. Materials with low thermal conductivities, such as plastics, can be used successfully provided that the fluid pipes are more closely spaced. The usual thickness of sheet metal flat plate absorbers is between 16 and 24 gauge. For materials with a high conductivity, such as copper, a thinner gauge can be used.

The chart by Steve Page from Solar Water Heating For the Handyman on the following page shows fluid tube spacing for a domestic hot water system. Note that copper, which has a high thermal conductivity, requires fewer pipes than does steel. Closer spacing of the tubes, though increasing the efficiency, will cost considerably more. These two factors, efficiency and cost, must be continuously balanced when designing a collector.



100% EFFICIENCY IS ACHIEVED BY COVERING SURFACE WITH BUTTED OR TOUCHING TUBES



80% EFFICIENCY IS ACHIEVED BY SOLDERING TUBES TO AN ABSORPTIVE SHEET OF EQUAL AREA SPACED AS FOLLOWS:

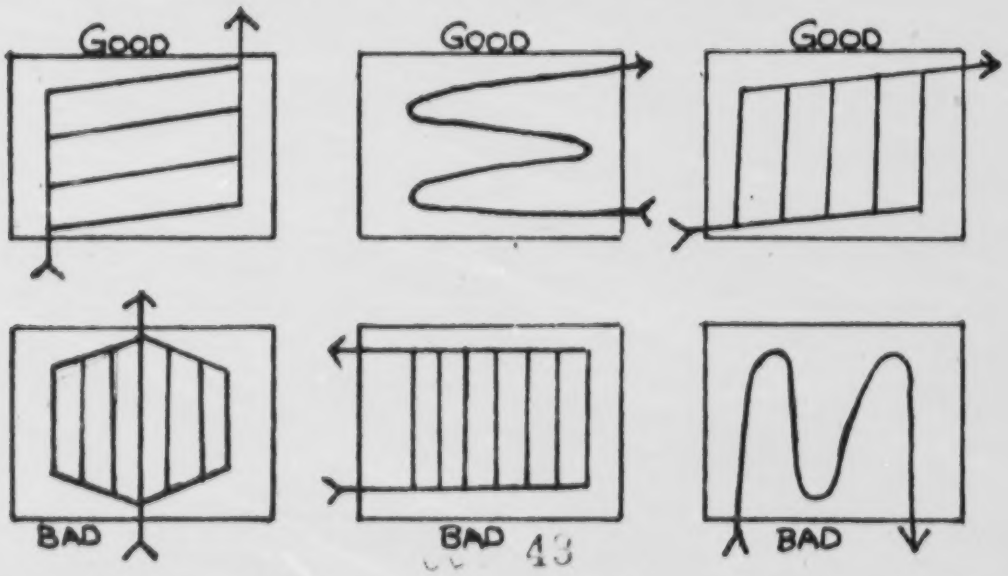
COPPER SHEET & TUBING	TUBES SOLDERED 12" TO 18" APART
ALUMINUM SHEET & TUBING	TUBES SOLDERED 10" TO 14" APART
STEEL SHEET & TUBING	TUBES SOLDERED 5" TO 6" APART

TUBE SPACING CHART

TUBE LENGTH	TUBE DIAMETER
60 FEET OR LESS	½ INCH I.D. OR LARGER
60-100 FEET	¾ INCH I.D. OR LARGER

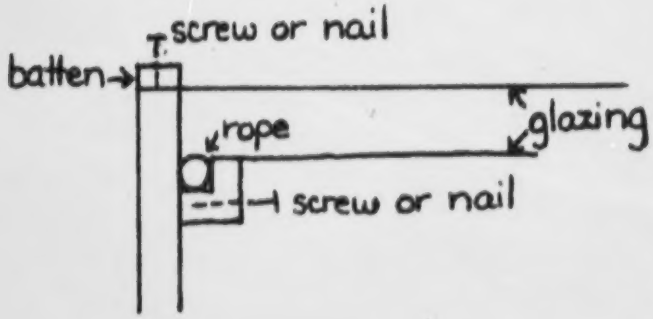
TUBE SIZING CHART

Usually 3/4" ID piping is suggested for a thermosyphon system with 1 1/4" ID header pipes. For a pump system, 1/2" ID is adequate. A GOOD CONTACT BETWEEN THE PIPES AND THE FLAT PLATE IS ESSENTIAL. Welding or soldering a continuous bead between tube and sheet provides an excellent contact, while clamping or gluing the pipes will descrease the efficiency by 20 to 35%. Designing a grid pattern for the fluid tubes is an important aspect of collector design. The following diagrams show some do's and dont's:



The actual collector size is determined by its heating use, its efficiency, and the availability of solar energy. For domestic hot water needs, it has been estimated that each person in the U. S. uses between 15 and 20 gallons of hot water per day. A sheet steel plate and pipe collector, working at temperatures 60° to 100° F. above ambient air temperature, should have about 1 sq. ft. of collector area for each gallon in storage. A conservation-minded family of four would need about 40 sq. ft. of collector area to meet 60% to 80% of their domestic hot water needs, while a not so energy-conscious family would need 60 sq. ft. It stands to reason that a larger collector is needed for areas receiving less sunlight (as much as 2 sq. ft./gal.) and that if the collector is used for the summer only, the collector size can be reduced. Keep in mind that an efficient collector needs less area to produce a given amount of hot water than an inefficient one.

The collector box serves to protect and insulate the flat plate much as the siding, roof, and insulation protect a house. The exterior made from metal, fiberglass, or wood should be water tight. Wood or metal battens screwed or nailed into the frame hold the glazing to the box securely. The same rules apply for mounting the glazing as for mounting window glass: always allow for expansion of the glazing material. The following diagram demonstrates how plastic films can be mounted:



The higher the design operating temperature of a collector, the more care must be taken in its design to reduce heat loss from the collector to its surroundings. The insulation used must be heat resistant for high temperature collectors and have a resistance to deterioration when wet. Standard fiberglass insulation with an R factor of at least 11 is adequate. Insert louvers should be used to ventilate the insulation space. 3/8" holes should be drilled into the collector space to allow condensation to escape. As with any house design, low cost and low maintenance designs should be stressed.

The efficiency of a flat plate collector is equal to $\frac{\text{Absorbed Energy}}{\text{Incident Energy}}$. An efficient collector then would be one which is dark in color and cool to the touch. Efficiency decreases as the collector temperature increases (Figure 10) It will also decrease if the storage fluid in a liquid system is unable to absorb the heat fast enough, allowing it to reradiate out into the collector. The fluid flow rate and the distance between the collector pipes are two factors which affect the flat plate's efficiency. By controlling the rate of flow in a pumped system, any desired average plate temperature can be maintained. In a thermosyphon system, where the rate of flow is determined by the difference in temperature between the collector and the storage tank, the flat plate temperature must be controlled by the fluid pipe size and spacing and grid design. Alignment of the collector also affects the efficiency. The highest efficiency for any given panel is achieved when the panel is perpendicular to the incoming sunlight and facing true south. This alignment is difficult to achieve on a continuous basis and therefore a fixed angle is chosen. The fixed angle for winter collection in the northern hemisphere is usually the latitude plus 15°. For year-round collection, a collector angle equal to the latitude works best. For small angles of misalignment, the loss of solar radiation is proportional to the cosine of the misalignment angle. It is obvious from Figure 11 that angle deviation is

not too critical a concern.

FIGURE II

Misalignment Angle	Percent of Maximum Solar Energy Intercepted
0°	100.0
5°	99.6
10°	98.5
15°	96.5
20°	94.0
25°	90.6
30°	86.6
35°	81.9
40°	76.6
45°	70.7
50°	64.3

This packet combines the explanation of the principles of heat transfer and storage with practical nuts-and-bolts considerations. Teachers should note that it isn't necessary to own a plumbing supply store in order to make low cost solar collectors. ALL SORTS OF JUNK CAN BE USED. Refrigerator cooling units and car radiators make excellent flat plate absorbers. 55 gallon drums, water beds, and empty plastic milk container bags painted black will heat water for a simple shower. Forced air collectors can be made using junk car heater fans and vacuum cleaner motors. Steve Baer from New Mexico, an early pioneer in making solar collectors out of junk, uses 55 gallon drums to collect and store heat for his house. For air type collectors, he has used car windshields as glazing material. Don Kent, in his solar Heating Supply Center in Weymouth, Mass., sells an air collector uses black painted beer cans as an absorber surface. IF A COLLECTOR IS CHEAP TO BUILD AND WORKS, USE IT! The projects in the activity section range from inexpensive junk collectors to solar domestic hot water units that can be built from standard building materials.

BIBLIOGRAPHY

1. Daniels, Farrington, Direct use of the Sun's Energy, Ballantine Books, 201 E. 50th St., New York, 1974. $1

Theoretical as well as practical explanations of all aspects of solar energy. It has detailed descriptions of flat plate collectors, contains illustrations, photos and extensive bibliography.

2. Hankins, William H. and Wilson, David, Practical Sun Power, Lorien House, P.O. Box 1112, Black Mountain, N.C. 28711, 1974. $4

Excellent book showing the "how tos" of making one spherical and two cylindrical parabolic collectors, a sheet metal solar oven, an inexpens solar hot water heater, a solar room heater that would attach to most windows, small solar furnace using a fresnel lens and a solar still, illustrations, photos and bibliography included.

3. Page, Steve, Solar Water Heating for the Handyman, Edmund Scientifi Co., Barrington, N.J. 08007, 1974. $4

Basic guide to flat plate collectors. Includes a number of low cost projects geared to the high school level.

4. Portola Institute, Energy Primer, Fricke-Parks Press, Inc., Freemont, California, 1974. "Solar Water and Air Heaters" pp. 6-12. $4

Excellent introductory book in solar,water, wind and biofuels. Contains information about manufacturers of alternate energy equipment as well as reviews of pertinent books.

5. State of Florida, Department of Administration, A Floridian's Guide to Solar Energy, Florida Solar Energy Center, 300 State Road, 401 Cape Canaveral, Florida 32920, 1975. $1

Excellent explanation of solar energy. Contains specific information about flat plate collectors. Has a number of diagrams and photos. This would make an excellent text book for unit on solar energy.

ACTIVITY LIST

A. Hot seat

B. Solar heating with junk: a dump picker's dream

C. Cardboard box collectors or how to race your collector and win

D. Simple thermosyphon system (for under $10.00)

E. Mail freebees

F. Solar still

G. Solar oven

H. Solar cabinet dryer for agricultural produce

I. Solar steam cooker

J. Solar room heater

K. Solar hot water heater

ACTIVITIES	MATERIALS	COST	TIME	PLANS & SUPPLEMENTARY INFORMATION
A Hot Seat	Thermometer	none	1 hr.	
B Solar Heating With Junk: A Dump Pickers Dream	See activity enclosed			
C Cardboard Box Collectors or How To Race Your Collector And Win	See activity enclosed		6 classes	
D Simple Thermosyphon System	See activity enclosed	$9.95	6 classes	1. pp. 75-89 2. 3. 4.
E Mail Freebees	See activity enclosed	$2.00	4 classes	
F Solar Still	Cost, materials and time depend on size of still. Cost range	From $2.00- $500.00		How To Make A Solar Still, Do-It-Yourself Leaflet #L-1 Brace Research Institute MacDonald College of McGill University Ste. Anne De Belevue 800 Quebec, Canada $1.25
G Solar Oven	16 sq. ft. 28 guage galvanized steel 22x24" window glass 12 sq.ft. 2" fiberglass insulation 1 spray can flat black paint assorted screws and nails	$20.00	10 hours	Solar Science Projects D.S. Halacy, Jr. Scholastic Book Services - 1974 $ .75

ACTIVITIES	MATERIALS	COST	TIME	PLANS & SUPPLEMENTARY INFORMATION
H Solar Cabinet Dryer For Agricultural Produce		$16.31		How to Make a Solar Cabinet Dryer For Agricultural Produce Leaflet #L-6 Brace Research Institute MacDonald College of McGill University Ste. Anne De Belevue 800 Quebec, Canada $1.25
I Solar Steam Cooker				Solar Steam Cooker Leaflet #L-2 Brace Research Institute MacDonald College of McGill University Ste. Anne De Belevue 800 Quebec, Canada $1.25
J Solar Room Heater	Cost, materials and time depend on size of collector			Practical Sun Power Rankins & Wilson Lorien House, Publisher P. O. Box 1112 Black Mt., N. Carolina 28711-1974 1. pp. 28-36 $4.00
K Solar Hot Water Heater	This is a well designed collector that could provide hot water for a family in Maine. The plans are well written and complete. The cost is about $104.00 for the collector.			Build Your Own Solar Water Heater Florida Conservation Foundation, Inc. Superior Minute Print Winter Park, Florida 32789 $3.50

Activity A HOT SEAT

On a sunny day locate ten cars sitting in direct sunlight in your school parking lot. Choose five with different colored interiors all of which are of approximately the same volume inside. Ask the owners of the cars to keep their windows rolled up from 10 A.M. to 2 P.M. At 2 P.M. record the temperatures. What do you observe? How do you explain the results?

Feel the various parts of one car. (windshield, hood, bumper, tires etc.) Make a list, in order of temperature, of 10 different parts. Why are some parts hotter than others?

On the way back into the school feel various colors and textures of the pavement and masonry on and around the building. Feel the school building's exterior, the doors and windows. List the various objects that you touch in order of temperature. Explain the results.

If you were hired to direct traffic standing on hot pavement during the summer would you wear a dark colored shirt or a light one to work?

Activity B

SOLAR HEATING WITH JUNK:
A DUMP PICKERS DREAM

Junk, you say? For many people it means only Saturday morning trips to the dump. To those uninitiated in the fun and rewards of dump picking, the words junk and dump hide the huge volume and richness of what we continually throw away as being of no further use to us.

Nothing could be further from the truth and we're going to prove it in this activity by using dump picker specials to build flat plate collectors.

Part 1

Fill four one gallon plastic or glass milk bottles with water.

Leave a little air in each container to allow for water expansion.

Paint three of the bottles with flat black paint. Leave one clear.

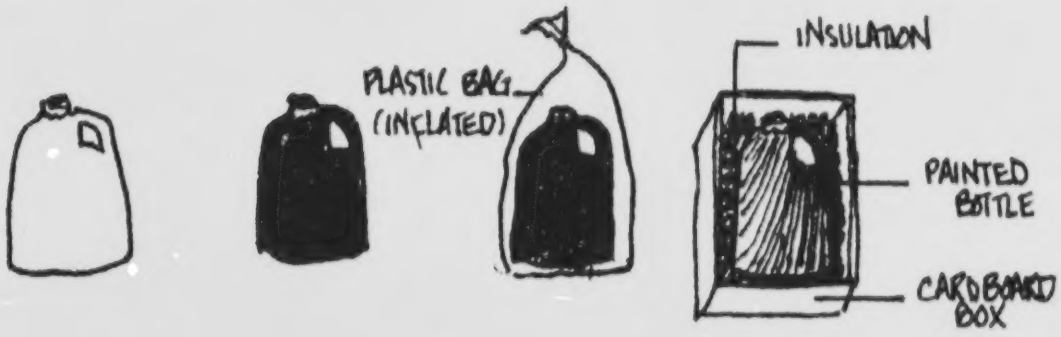
Place one of the painted containers inside of a clear plastic bag and inflate and seal the bag. Place another black container into a box slightly larger than the bottle. Fill the space between the bottle and the box with some sort of insulation. (cloth or newspaper will work fine for this).

Tape a glass or plastic cover over the insulated box.

Take all four containers outside and face them into the sun.

Record the temperature in each container at the end of one hour.

Explain the results you have found.



1. Which bottle got the hottest? How could you improve this solar collector so that it would produce hot water faster? What other materials could be used to make it more durable and easier to handle?
2. Which collector would work best during the winter? How would you prevent the water from freezing?
3. Would the water in the bottles heat up on a cloudy day?
4. Can you think of some use for this type of collector?

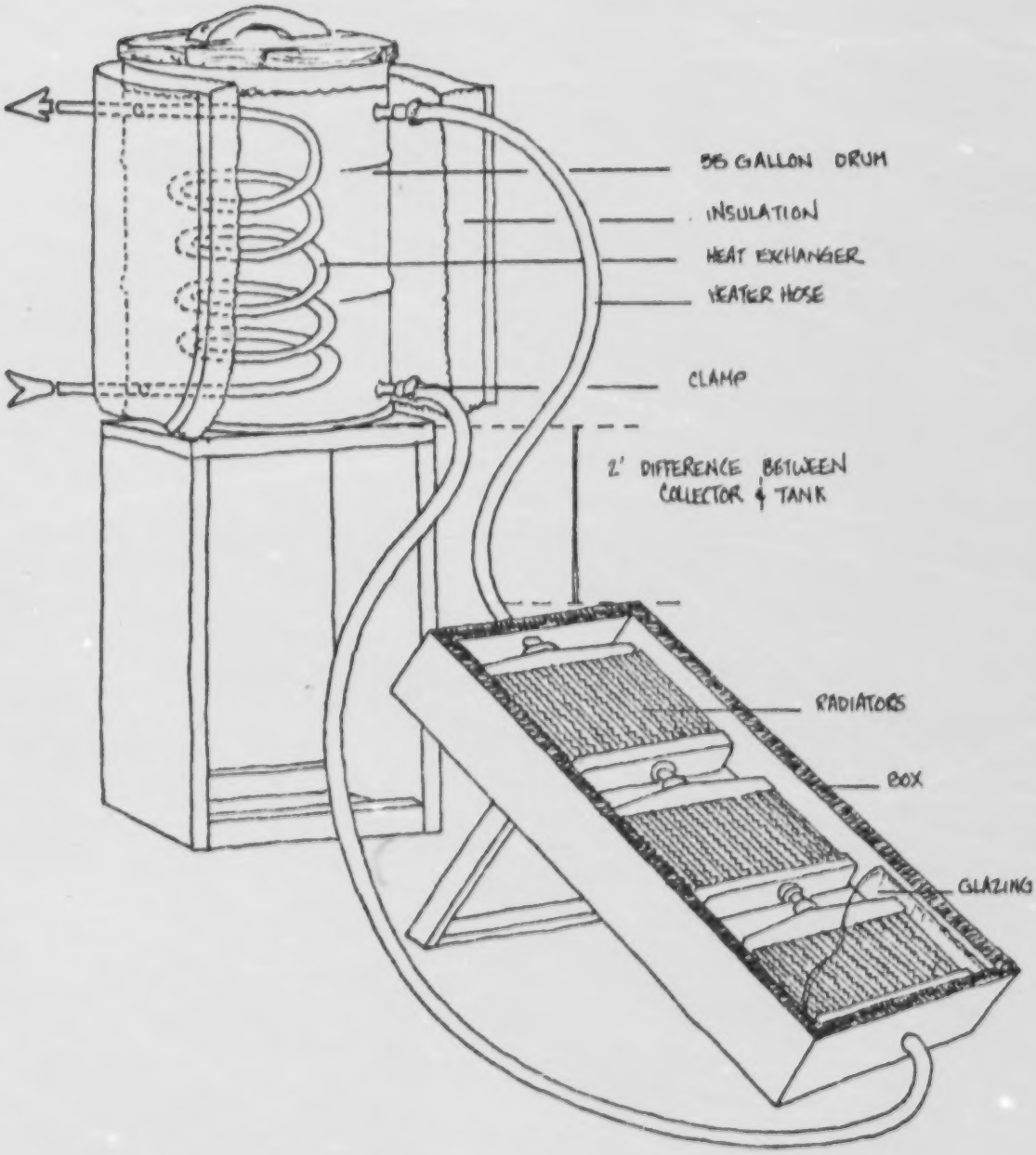
These collectors look mighty simple but they are actually models of collectors which are working today in the U.S. to provide heat for houses and hot water for washing. These collectors are called passive solar collectors because they use no pumps or piping to circulate the solar heated water to where it is needed. The collector and the storage unit are together. Steve Bear in New Mexico uses a wall of 55 gallon drums mounted behind a large glass window to capture solar heat for his house during the day. At night a large insulated panel covers the windows and the hea in the drums is radiated into the house. Harold Hay uses the same system on the roof of a house he built. Black water beds store the heat instead of drums, allowing the heat down into the rooms at night. Collector C is similar to a hot water sun shower sold by Solar Usage Now, Box 306, Bascom, Ohio 44809 for $8.95. The shower consists of a plastic bag which is clear on one side; and black on the other with a shower nozzle mounted on the bottom. Exposed to the sun for three hours with the clear side up and the dark side down it can provide two campers with enough hot water for showers. (Why is one side of the plastic bag clear?)

Bottles aren't the only things that make good collectors. Here is a list of other containers that you might like to experiment with: Plastic milk bags - the kind used in cafeteria milk dispensing machines, 55 gallon drums, old hot water tanks, water beds, truck inner tubes.

Part 2

Heat exchangers make excellent flat plate collectors. (Why?) In this part you will use junk radiators and a 55 gallon drum to make a thermosyphon solar hot water heater. The system can be used as a preheater for an existing hot water heater or as a hot water heater for one or two people. Patch any leaks that you find in the radiators with solder. Join radiators together in series. This can be done either of two ways. The first is simply to join the input and output holes from one radiator to the next using standard radiator hose and clamps. The second method eliminates the need for a large collector box which must accomodate the hoses joining the radiators from the back. Seal input holes, output holes and intake holes. Drill holes in top and bottom of the radiator and insert and solder short pieces of copper pipe. Use standard radiator hoses and clamps to join radiators together.

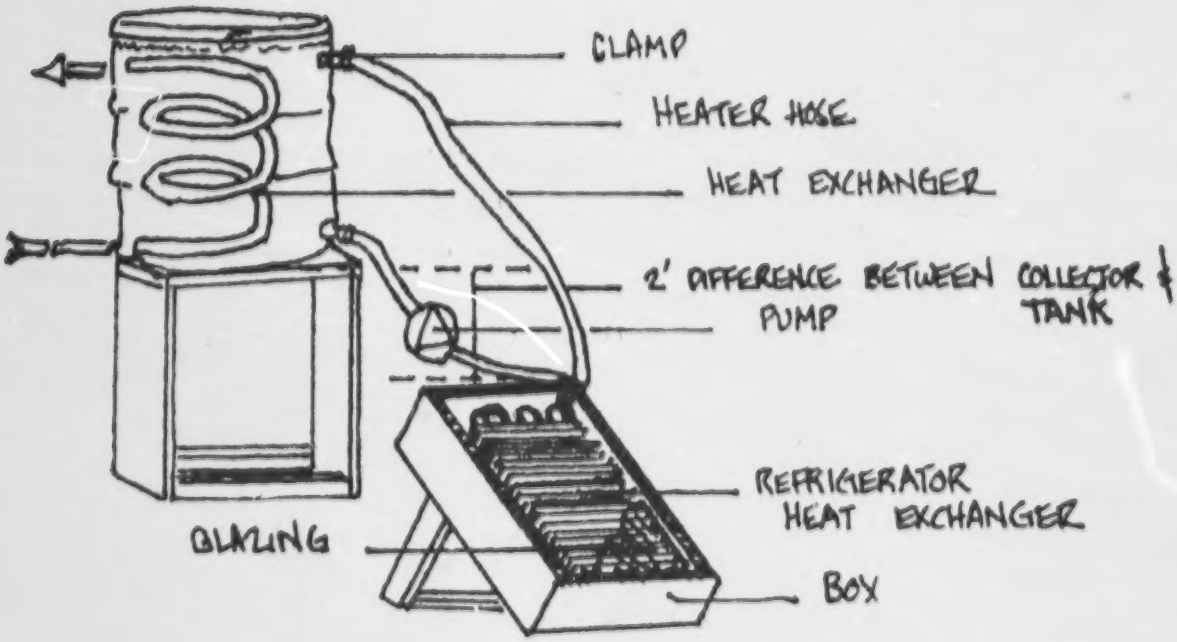
Design and build an insulated box for the radiator collector plate. Paint the inside of the box black. (Why?) An old refrigerator door might serve as the box with the addition of sides. If you can't scrounge anything use plywood with fiberglass insulation. Old storm windows or polyethylene plastic will serve as a cover glazing provided that they fit tightly over in the insulated box. The diagram on the next page shows how the collector panel is attached to the storage tank. 1/2" diameter steel pipes brazed into a 55 gallon drum at the top and at the bottom serve as the inlet and outlet openings. Radiator hose is used to connect the collector to the storage tank. Inside the tank is a heat exchanger made from soft copper pipe which is


55 GALLON DRUM
INSULATION
HEAT EXCHANGER
HEATER HOSE
CLAMP
2' DIFFERENCE BETWEEN COLLECTOR & TANK
RADIATORS
BOX
GLAZING

hooked into an existing hot water system. (Can you suggest a reason why a heat exchanger is necessary when using car radiators?) Insulation should be wrapped around the radiator hose as well as the storage tank.

Can you think of any other heat exchanger in the 55 gallon tank that would work? Could an old hot water tank be used instead of the 55 gallon drum? How would it be hooked up?

A refrigerator cooling grid also makes a good collector panel. See the following diagram:



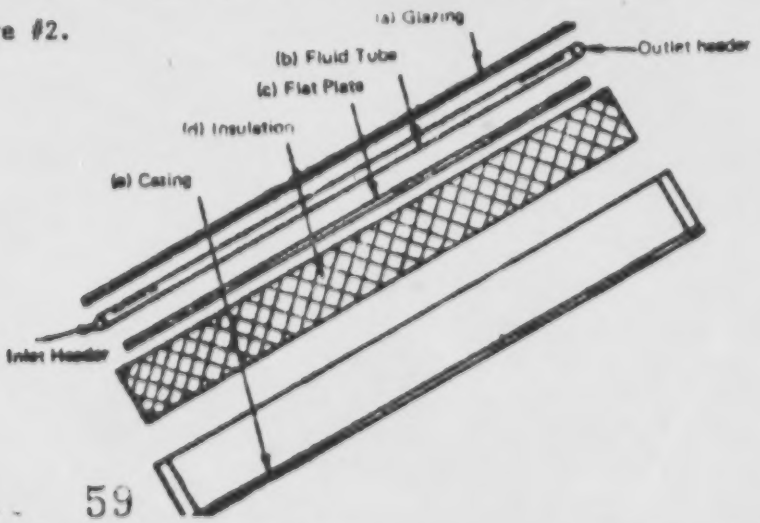
Activity C

CARDBOARD COLLECTOR OR HOW TO RACE YOUR COLLECTOR AND WIN

It's 2:20, the final bell has rung and you are free. As the untuned Chargers and mufflerless Cameros jocky for position to peel out in the parking lot you run into the shop and grab your newly constructed flat plate collector only to find that you had been creamed at the starting line.

This may sound a little hokey but you can race collectors. Let me explain. When you design a solar flat plate collector there are two ways to determine how efficient it is. The first way is to calculate the amount of solar radiation the collector can receive, the amount of energy the flat plate can absorb and the heat losses that will occur through the glazing and sides. The second method is simply to race two collectors side by side. The winner is the one which generates the most heat for a given amount of time.

Before we go over the rules of the competition lets go over solar flat plate collector theory. There are four major parts to a collector panel: (1) A glazing, consisting of a substance which will allow light to pass through, yet prevent the reradiated long wave heat radiation from escaping, (2) A fluid tube or air duct grid mounted at least 1" below the glazing which captures and transports the heat to either the living space or a storage area, (3) A black flat plate which will absorb the radiation and conduct or convect it to the transporting medium (air or water), and (4) A casing which shields, protects and insulates the components from the outside weather. See Figure #2.



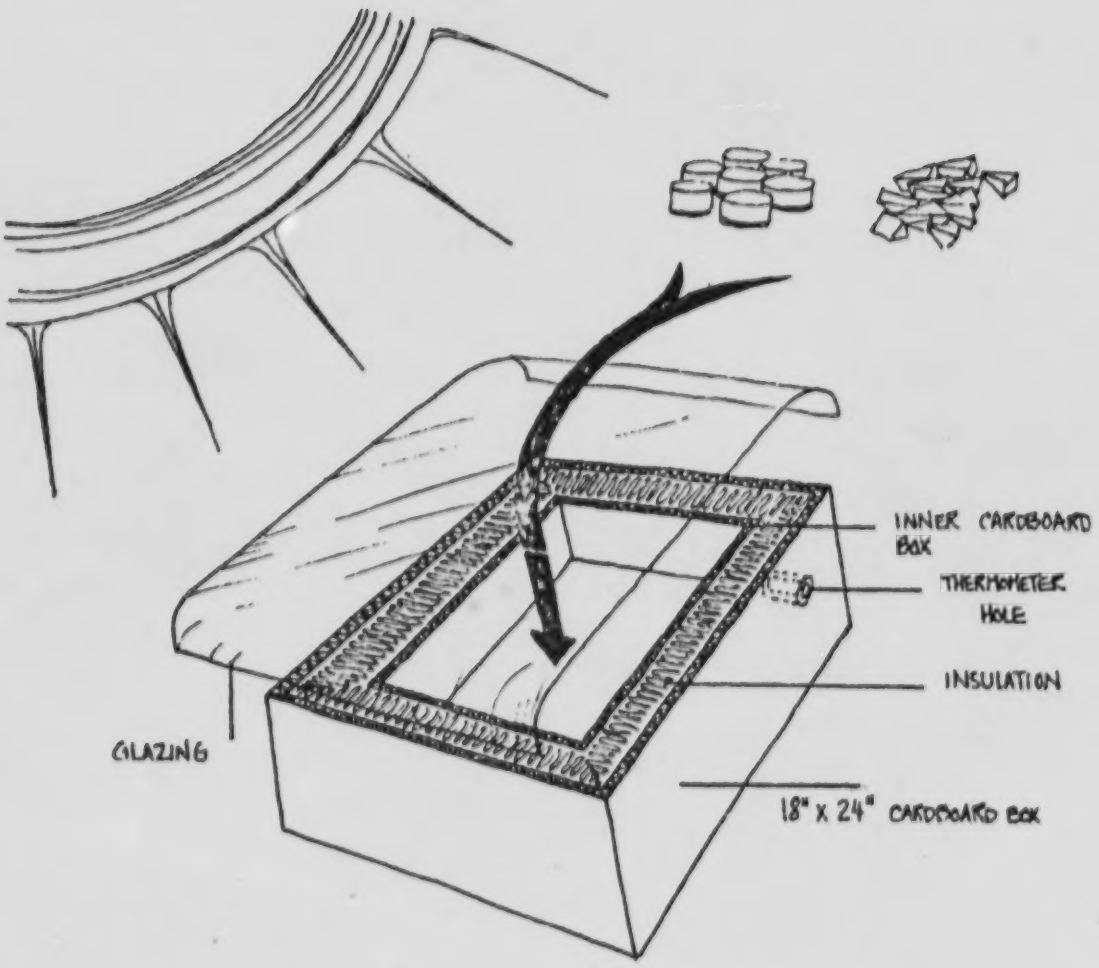
Normally heat generated in the panel would be transferred to air or water and circulated to an insulated storage area. The collectors in this activity are sealed so that the heat generated inside the collector can be measured.

RULES OF THE COMPETITION

Each student in the class is to build a flat plate collector using a cardboard box of a standard size. (approximately 18" x 24" x 12"). During a two week period prior to the race each student experiments with various designs. The object is to design a collector that will achieve the highest temperature after a one hour period in the sun. The following outline shows the various things that you should experiment with:

1. Glazing
    - A. Type of glazing-polyethylene, Tedlar, Kalwall fiberglass, glass
    - B. # of glazings-1,2, and 3 layers. (Leave at least 1/2" between each layer).
2. Insulation
    - A. Type of insulation - fiberglass, newspaper, sawdust, styrofoam
    - B. Amount of insulation
3. Absorber plate
    - A. Type of absorber material - wood, metal, plastic
    - B. Color of material
    - C. Texture of material - beer cans stapled to absorber plate, wooden blocks, cardboard ribs, baby food jars.
4. Reflective fins (reflective surfaces attached to the sides which reflect light into box).
    - A. Reflective material - aluminum foil, aluminized mylar, building foil
    - B. Size of reflective fins

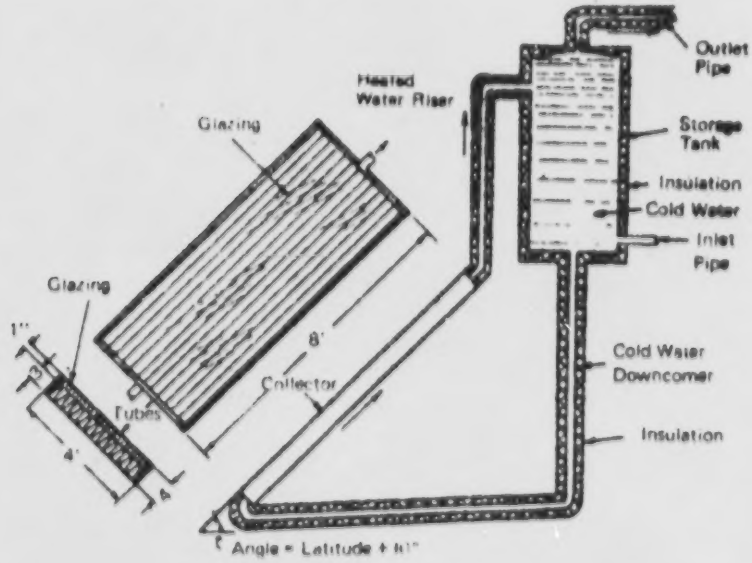
The diagram on the following page shows what a typical collector might look like.



Cut a 1/2" hole in the side of the collector large enough for a thermometer. Face all the collectors toward the sun at the same angle and race for 1 hour.

Activity D THERMOSYPHON SYSTEM

Heat travels from warm to cold areas creating convection currents. A thermosyphon system uses natural convection to move a fluid (either air or water) through a flat plate collector and into a storage tank. Figure A shows a schematic of a typical thermosyphon system. Water enters at the bottom of the collector is heated and rises gradually through the collector pipes and into the storage tank, where it remains until it is needed. A thermosyphon, because it needs no pump, is attractive to homeowners concerned about initial cost and overall maintenance of solar domestic hot water systems. A disadvantage of a thermosyphon system is that the rate of flow of the fluid is determined by the difference in temperature between the collector fluid and the tank. As the tank temperature approaches the collector temperature the flow rate slows down causing the collectors efficiency to go down also. Another disadvantage in that there's no control of the circulation which continues even when collector is cool, thus cooling off stored water.



#10 cans soldered together are used for both the storage tank and the gravity feed tank. The gravity feed tank provides pressure and intake water for lower tank. (What is the advantage of having some water pressure in this thermosyphon?) 1/2" pipes are soldered into holes cut in the appropriate places in the tanks. Screw clamps, fasten garden hose to the collector and storage tanks. The flat plate collector is made from scrap 1/2" ID copper pipe and an insulated plywood box. Glass or plastic is used as a glazing material. Diagram B shows exploded view of collector.

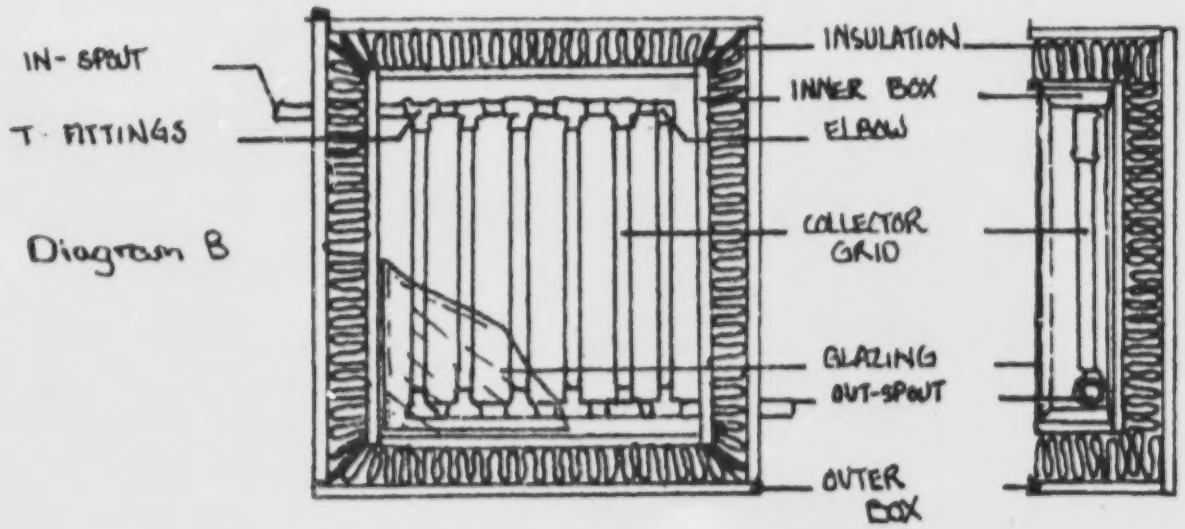
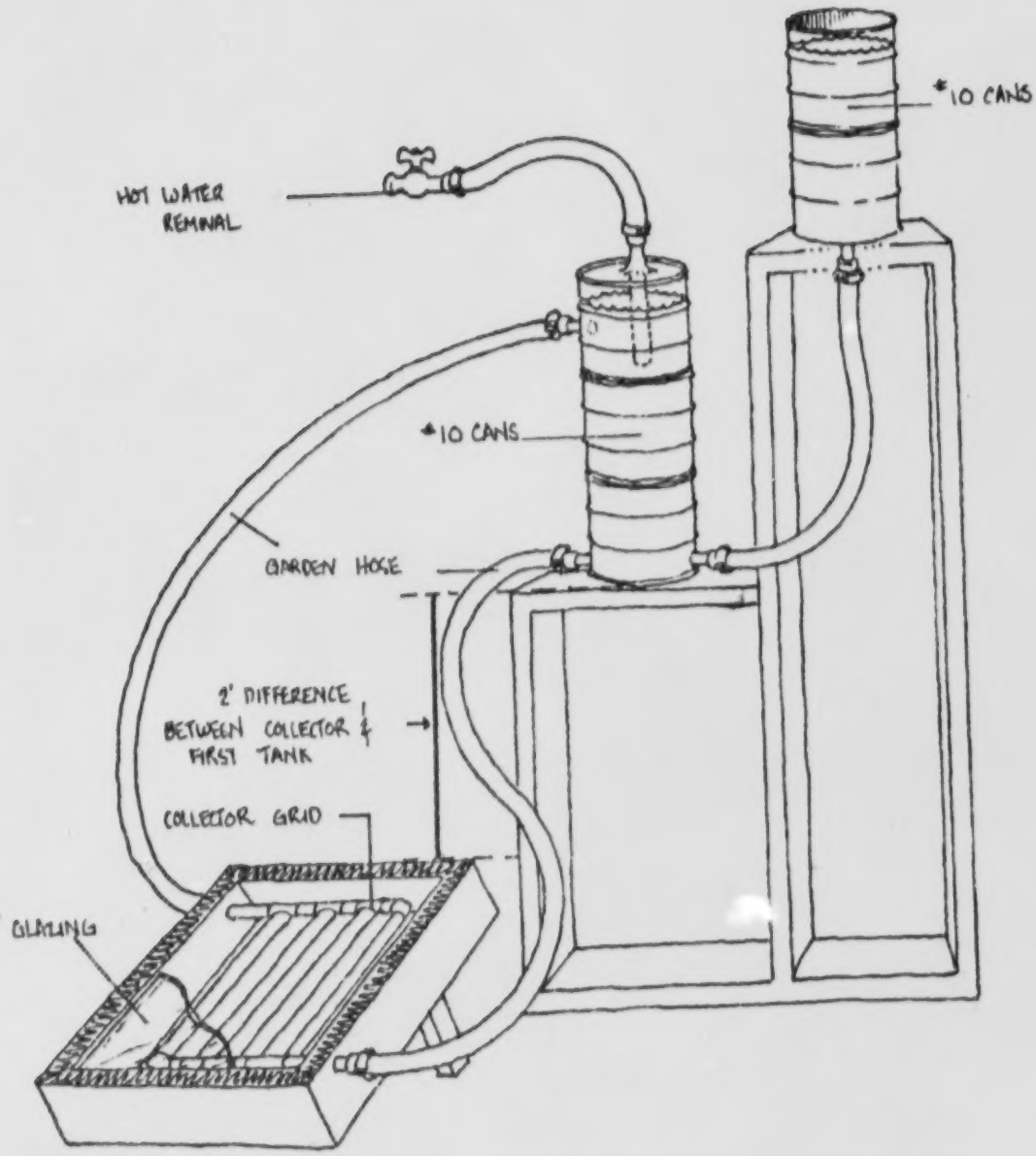


Diagram B

Questions:

1. How much would the solar collector weigh if it were enlarged to 3' x 8' assuming that the pipe sizing remained the same?
2. How much would a 40 gallon tank weigh for such a collector?
3. Would an FmHA type house support such a collector on its roof?
4. How could the flow rate be increased in the collector without using a pump?
5. How might the collector be improved so that its efficiency is increased?


*10 CANS
HOT WATER
REMNAL
*10 CANS
GARDEN HOSE
2' DIFFERENCE
BETWEEN COLLECTOR &
FIRST TANK
COLLECTOR GRID
GLAZING

Activity E Mail Freebees

Although there are solar hardware stores that sell a variety of flat plate collectors and componants, the average homeowner in Maine does not have access to these stores. In order to compare cost, construction and durability of various models, it is necessary to write manufacturers for their advertising brochures. Be sure to request the specifications on each type of collector, including the manufacturer's efficiency data.

Write letters to the following manufacturers and ask for their descriptive materials.

1. Geo. H. Brittain and Son, Inc.
   Box 334
   Boothbay Harbor, Me 04538

2. John Dumont
   Dumont Steel
   Monmouth, Me 04259

3. Peters' Gas and Oil
   Bridge Street
   Fairfield, Me 04937

4. C. M. Thorton
   Thorton Sheet Metal
   Waterboro, Me 04087

5. Kalwall Corp.
   Box 237
   1111 Canadian Road
   Manchester, NH 03105

6. Solar Energy Co.
   Deerwood Drive
   Merrimack, NH 03054

7. Garden Way Laboratories
   P.O.Box 66
   Charlotte, Vt. 05445

8. Sun Works, Inc.
   669 Boston Post Road
   Guilford, Ct. 06437

9. Olin Corp.
   120 Long Ridge Road
   Stamford, Ct 06904

10. Dixon Energy Systems
    P.O.Box 304
    Conway, Ma 01341

From their information, complete the enclosed table.

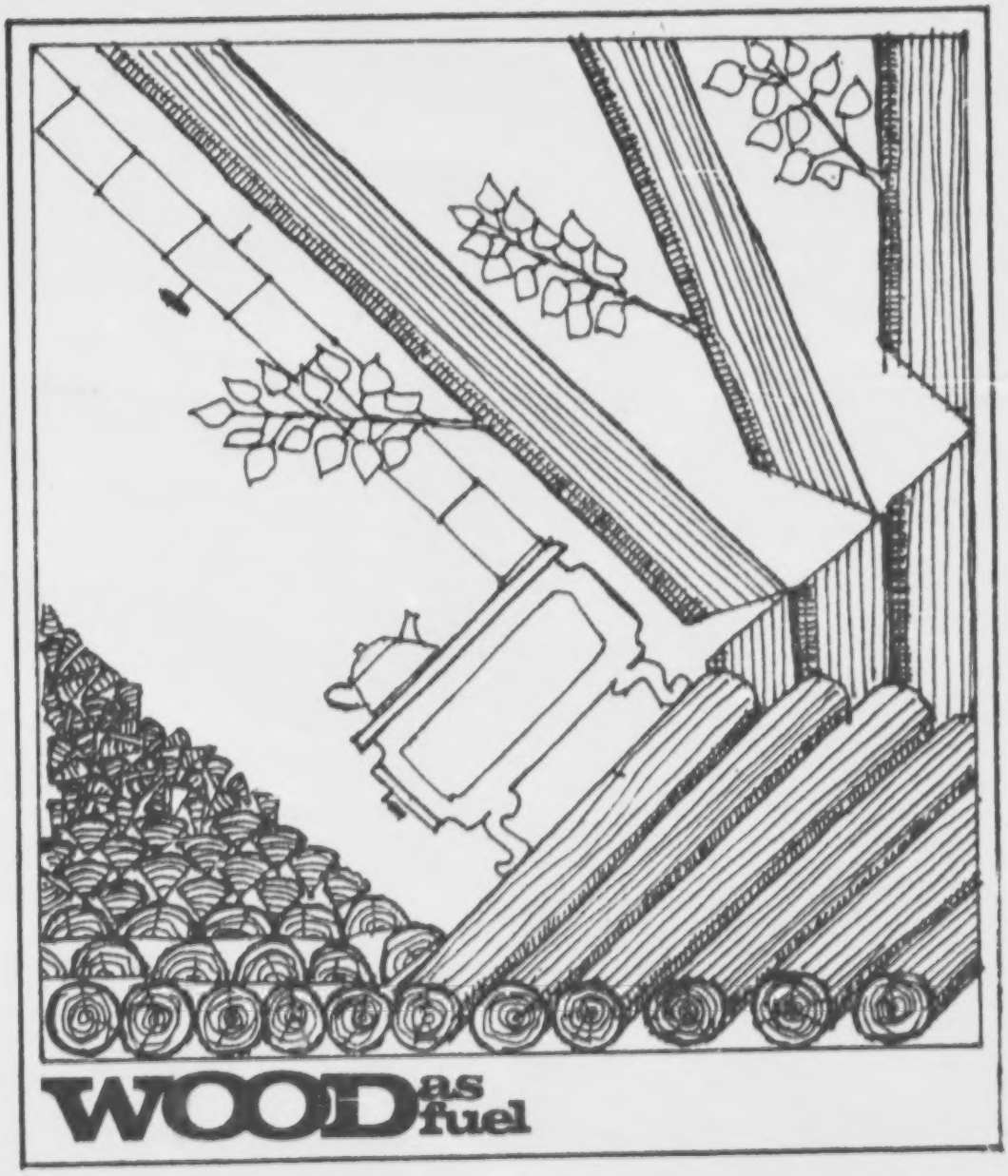
On the basis of the literature you have received, which collector(s) would best serve the hot water needs of your family? How would this collector

(Cont.)

hook into the existing hot water system in your home? How much would it cost? What would the pay back period be, that is, how much money would your family save per month assuming that the collector will last 10 years and the cost of gas/oil goes up in price by a 6% inflationary rate each year?

If you were going to solar heat the shop in your school building, how much collector area would you need? How would you attach collector to the building? Could you modify the collector design so that cheaper materials could be used?

MANUFACTURER	LOCATION	COST/FT^2	USE SELECTIVE COATING	# AND TYPE OF GLAZINGS	WEIGHT/FT^2	AIR OR WATER TYPE	SPACE HEATING OR DOMESTIC HOT WATER TYPE	EFFICIENCY


WOOD as fuel

Wood heat makes sense for Maine. After all, Maine is the most heavily forested state in the nation with 87%, or 17.7 million acres, of its land forested. Seven million acres of this total is hardwood forest. More effective use of this natural resource can have multiple benefits. It can, 1) reduce over-dependence on foreign oil, 2) stimulate local wood harvesting industries, 3) increase the utilization of poorly shaped trees and 4) increase woodlot productivity. This packet deals with the economics of using wood as a fuel and some of the techniques now employed to make efficient use of its heating potential. An annotated bibliography lists pertinent books and magazines dealing with wood heat. A student activity section provides projects which will give a high school student a better understanding of wood as a home heating fuel for Maine.

Wood energy is just another form of solar energy. The chemical reaction of photosynthesis converts carbon dioxide, water and minerals into hydrocarbons, (such as cellulose and lignin) and oxygen, with the help of energy from the sun. All parts of a tree - the leaves, trunk and roots - store energy in the form of wood. A fallen tree will release this energy slowly when bacteria and fungi oxidize the cellulose and lignin molecules. Man can utilize this energy rapidly by distillation of the cellulose into such fluid fuels as methanol or by burning the wood in furnaces and stoves. In either case, the end products of carbon dioxide, water and energy are the same. For Mainers, the present system of harvesting and transporting the wood for use in home wood burners represents the most economical way to immediately tap this resource.

The heat energy stored in one pound of oven dry wood is the same, regardless of species. Variation in BTU content per cord is due to the difference in density that occurs between species. The actual usable BTU value depends on the

moisture content of the wood, shape of the firewood pieces, efficiency of the stove, chimney draft and how well the heating unit is operated. Despite the large number of variables, it is possible to estimate the relative costs per heat produced for both oil and wood.

A convenient unit is used by both fuel dealers and heating engineers to compare fuels; 1 Therm = 100,000 BTU. The therm is a popular unit because home heating oil (#2 fuel oil) contains about 140,000 BTU per gallon which, when burned in a 70% efficient furnace, yields 1 therm of useful heat. For the therm content of air dried wood, refer to Table II on page 4.

Next, to find the cost per therm of useful heat calculate the following ratio:

$$\text{COST PER THERM USEFUL HEAT} = \frac{\text{COST PER FUEL UNIT}}{\text{THERM CONTENT PER UNIT X BURNER EFFICIENCY}}$$

(OIL @ $.42/GALLON)
(EFFICIENCY = 65%)

$$\text{COST PER THERM USEFUL HEAT} = \frac{\$0.42}{1.40 \times 0.65} = \$0.46 \text{ per THERM}$$

(ELM WOOD @ 20% MOISTURE)
(EFFICIENCY = 50%)
($60/CORD)

$$\text{COST PER THERM USEFUL HEAT} = \frac{\$60.00}{238 \times 0.50} = \$0.50 \text{ per THERM}$$

In other words, for the specific efficiencies and prices given, it would be cheaper to buy oil than elm.

Table I from David Haven's The Woodburners Handbook shows the relationship between the weight of green and air dried wood and their prospective BTU values.

TABLE I

Approximate weight and heating value per cord of different woods, green and air-dry

SPECIES	WEIGHT		AVAILABLE HEAT	
	GREEN	AIR-DRY	GREEN	AIR-DRY
	Pounds	Pounds	Million BTU	Million BTU
Ash	3,840	3,440	16.5	20.0
Aspen	3,440	2,160	10.3	12.5
Beech, American	4,320	3,760	17.3	21.8
Birch, yellow	4,560	3,680	17.3	21.3
Elm, American	4,320	2,960	14.3	17.2
Maple, red	4,000	3,200	15.0	18.6
Maple, sugar	4,480	3,680	18.4	21.3
Oak, red	5,120	3,680	17.9	21.3
Oak, white	5,040	3,920	19.2	22.7
Pine, eastern white	2,880	2,080	12.1	13.3

Air-dry means with 20 per cent moisture in terms of oven-dry weight, or 16.7 per cent in terms of total air-dry weight. One BTU (British thermal unit) is the amount of heat required to raise the temperature of one pound of water 1F°. Available heat equals calorific value, minus loss due to moisture, minus loss due to water vapor formed, minus loss in heat carried away in dry chimney gas. Flue temperature 450°F., no excess air. (Data supplied by Forest Products Laboratory, Madison, Wis.)

Green elm liberates only 83% of its fuel value compared to 20% air dried wood. (14.3 BTU value green wood ÷ 17.2 BTU value dry wood X 100) The price per cord equivalent to oil for this green elm is $42.62! It has been said that wood heats you three times - once when you chop it, once when you burn it, and once when you haul out the ashes. If you're not careful, you can also get burned a few times: once if you buy a short cord, once when you get less heat per dollar for the green wood you bought, and again when you can't get that green wood to burn!

Table II shows the relationship between species, pounds per cord, useable fuel value per cord and the price per cord equivalent to oil at 42¢ per gallon. Keep in mind that this table was computed using 65% oil burner efficiency and a stove efficiency of 50%. Furnace efficiencies typically range between 50%-75% while wood stove efficiencies range from 15% for a fireplace up to 85% for air tight stoves under optimum conditions.

TABLE II

SPECIES	AVERAGE DENSITY lbs/cord 20% Moisture CONTENT	POTENTIAL USEABLE FUEL VALUE PER CORD (BTUs)	PRICE/CORD @50% EFFICIENCY EQUIVALENT TO OIL AT 42¢/gallon
White Oak	4,400	30,800,000	$71.14
Sugar Maple	4,000	28,000,000	$68.61
American Beech	4,000	28,000,000	$64.68
Red Oak	3,900	27,300,000	$63.06
Yellow Birch	3,800	26,600,000	$61.44
White Ash	3,700	25,900,000	$59.83
American Elm	3,400	23,800,000	$54.97
Red Maple	3,400	23,800,000	$54.97
Paper Birch	3,400	23,800,000	$54.97
Douglas Fir	2,900	21,400,000	$49.43
Eastern White Pine	2,200	15,800,000	$36.49

Statistics on the weight and density of cord wood vary from study to study as Table I and Table II demonstrate. These discrepancies can be attributed to several possible causes: 1) the solid volume of a cord of wood varies from 77 to 96 cubic feet depending upon how it is split and stacked, 2) the density of the wood can vary from location to location within species.

The price of firewood is usually a reflection of the cost of purchasing the standing trees and the costs of harvesting and trucking the wood to the consumer. The following table showing estimated firewood costs was compiled by a land management company with logging operations in both New Hampshire and Maine.

TABLE III

FIREWOOD
Estimated Costs

PER CORD:	LOG LENGTH	FOUR FOOT
Labor	$11.00	$14.00
Payroll Taxes:		
FICA @5.85%	.64	.82
Federal and State Unemployment @3.2%	.35	.45
Workmen's Comp. Insurance @12%	1.32	1.68
Skidder Costs:		
Fuel, Maintenance & Repairs	1.20	1.20
Depreciation	3.00	3.00
Total Labor and Machinery Costs	$17.51	$21.15
Stumpage	6.00	6.00
Total Cost at Landing	$23.51	$27.15
Trucking	7.00	8.00
Total Cost	$30.51	$35.15

In general, the further the consumer is from the source of wood, the higher the transportation cost. This transportation cost is no less than $5.00 per cord. In addition, the stumpage cost (i.e.; the price paid for the standing trees) varies from place to place. In the central coastal sections of Maine the stumpage fee is between $3.50 and $4.00 per cord. In some places in New Hampshire, this fee can be as high as $10.00 per cord.

The total estimated cost of $35.15 per cord does not include cost of cutting and splitting the wood into stove size pieces. It is obvious that the profit margin is slim for the firewood seller. At today's prices, the cost advantage to the consumer in terms of BTU/$ is not great. Buying firewood makes sense today as long as the wood can be harvested, cut, and split and delivered for less money per useable BTU than oil. Wood heat is ideal for those who own a wood lot and have the equipment and the time to do the harvesting. As our oil reserves dwindle and the cost rises, it is inevitable that wood will be used to heat more homes in Maine.

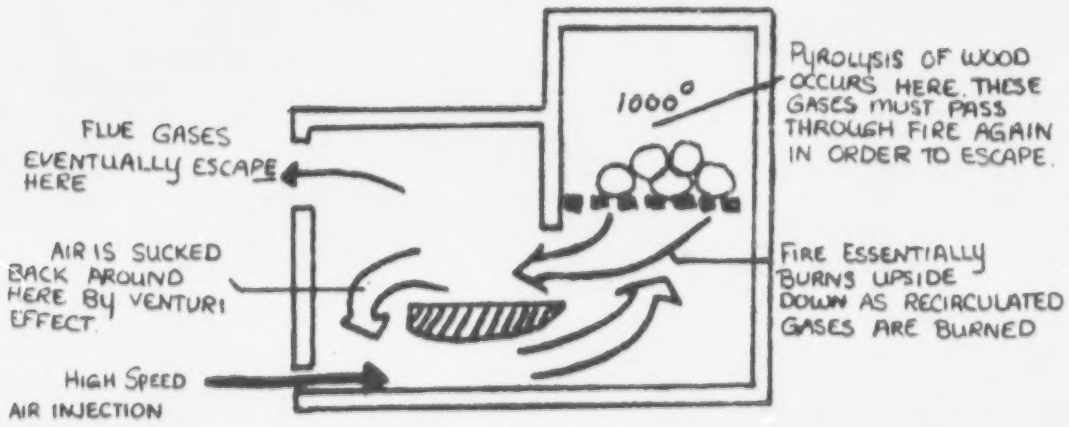
Wood burning stoves, unlike oil or coal furnaces, must accommodate variations in fuel density, moisture content, and size and shape of combustible pieces. In addition, wood stoves must be designed to efficiently extract energy during the four stages of wood pyrolization which occur simultaneously within a wood stove. In the first stage, which begins about 250°F, free water is evaporated from fiber cell walls and cell cavities. The second stage begins when volatile gases, which comprise approximately 50% of the heat value of wood, are driven off. These volatile gases require for their combustion two conditions: 1) Temperatures over 1,100°F and 2) oxygen. The charcoal, pure carbon, and minerals burn between 1000°F and 2000°F.

The efficiency of a wood stove is expressed as the percent of useable fuel value that is transferred to the living space. An efficient stove, therefore, must use both the energy stored in the volatiles as well as from the charcoal. Creosote, the black sticky liquid that dribbles out of stove pipes is formed when unburned, volatile gases rise into the chimney and condense. Creosote build-up is a sign of low stove efficiency. There are a number of partial solutions to the creosote problem. The best solution is to use a stove which is designed to burn the volatiles. Opening the damper and drafts when wood is first introduced into the fire will provide oxygen to create higher temperatures during the time of maximum volatile release. Higher temperatures usually allow a more complete burn. Increasing stove pipe temperatures by using heavier gauge stove pipe or insulated stove pipe will help prevent volatile gas condensation in the flue. One final solution is to use dry wood. Green or wet wood releases excessive moisture upon burning, which in turn cools the fire, causing incomplete combustion and creosote build-up.

The wood furnace designed by Professor Richard Hill of UMO for the new Audubon building in Falmouth uses two important design features to maximize efficiency. Fuel combustion is separated from the heat transfer system. Heat generated in the insulated furnace firebox is piped through two 70' long galvanized flue pipes mounted over a crushed rock storage bed used to store solar heat from the 2000 square feet of flat plate collector on the building's south side. Fans blowing over the hot pipes transfer the heat into the heat storage area. Flue gases leave the furnace at temperatures approaching 1000°F and cool to approximately 150°F before being drawn out the chimney. This system takes advantage of the energy released when water vapor condenses as the temperature reaches dew point. An induced draft fan is necessary to suck the cool low buoyancy gases up and out of the chimney.

Efficient combustion is facilitated in two ways. A forced draft fan blows air into the firebox at 400-500 feet per second providing sufficient oxygen for a rapid high temperature burn. Hot exhaust gases are sucked back into the fire by the partial vacuum created by the forced air stream (the Venturi effect). Very little creosote is created in this high temperature combustion process. The tremendous amount of heat produced would be excessive if delivered at one time to the building and is therefore stored in the rock storage bed to be used when needed. Diagram A shows a schematic of the Maine Audubon furnace.

DIAGRAM A

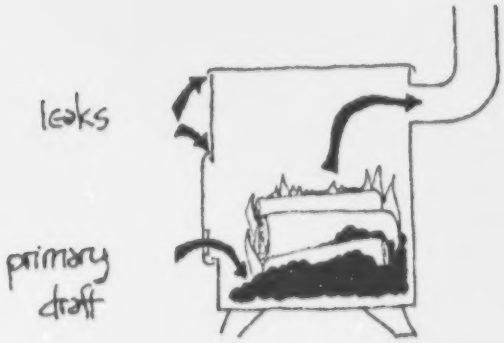

PYROLYSIS OF WOOD OCCURS HERE. THESE GASES MUST PASS THROUGH FIRE AGAIN IN ORDER TO ESCAPE.
1000°
FLUE GASES EVENTUALLY ESCAPE HERE
AIR IS SUCKED BACK AROUND HERE BY VENTURI EFFECT
FIRE ESSENTIALLY BURNS UPSIDE DOWN AS RECIRCULATED GASES ARE BURNED
HIGH SPEED AIR INJECTION

Most commercial stove designs are a compromise between efficiency, cost, and convenience. Leaky, fast burning stoves will burn large quantities of wood at high temperatures causing very little creosote build-up thereby avoiding the maintenance problems associated with this problem. They also lose a great deal of useable heat up the chimney. On the other hand, a slow burning air tight stove, with the damper shut, will not reach high enough temperatures for combustion of volatiles.

This inefficient burning produces a build-up of creosote in the flue. A brief run down on some of the major designs of wood stoves on the market today follows.

The simple box stove as pictured in diagram B has been used for decades here in Maine. It is usually the least efficient stove as it has poor control over oxygen intake.

DIAGRAM B



In air tight stoves, air enters only through designated air inlets. By regulating the air intake either automatically thermostatically or manually, the rate at which the fire burns can be controlled. On both stove designs represented below, there are provisions for air intake for the secondary burning of the volatile gases. Both the baffles and the placement of the air intakes slow down and divert the vertical movement of gases. Such design features increase secondary burn by lengthening the time hot gases remain in the stove.

DIAGRAM C

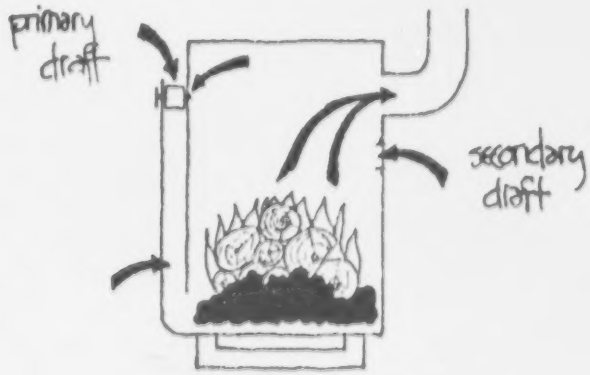
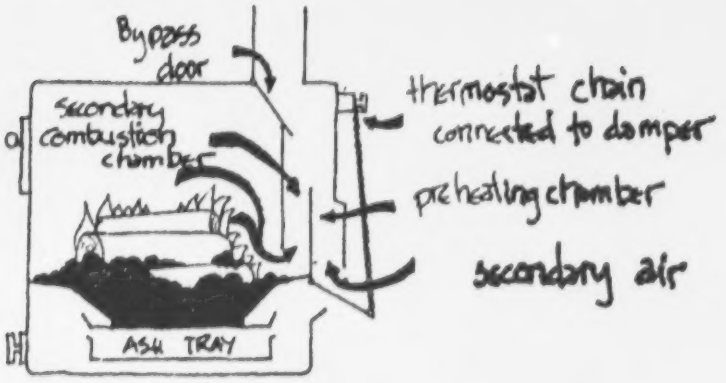
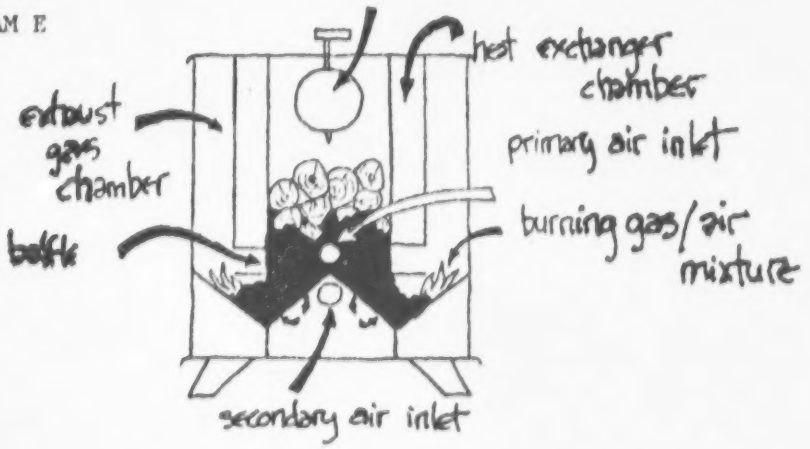


DIAGRAM D



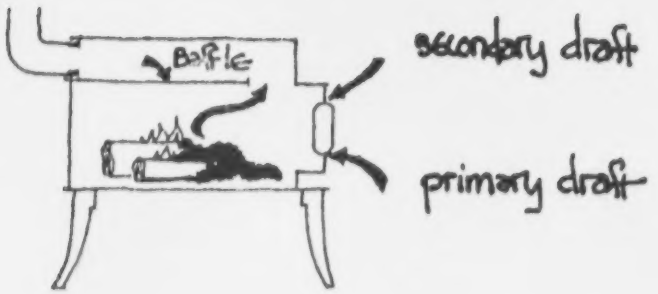
In the down draft airtight stove shown below, the primary air intake is located above the fire. The draft flows down through the coals pulling volatiles into a lower chamber where secondary draft air is provided so that the gases can be burned. Heat exchanger chambers help to extract the heat before it is allowed to excape.

DIAGRAM E



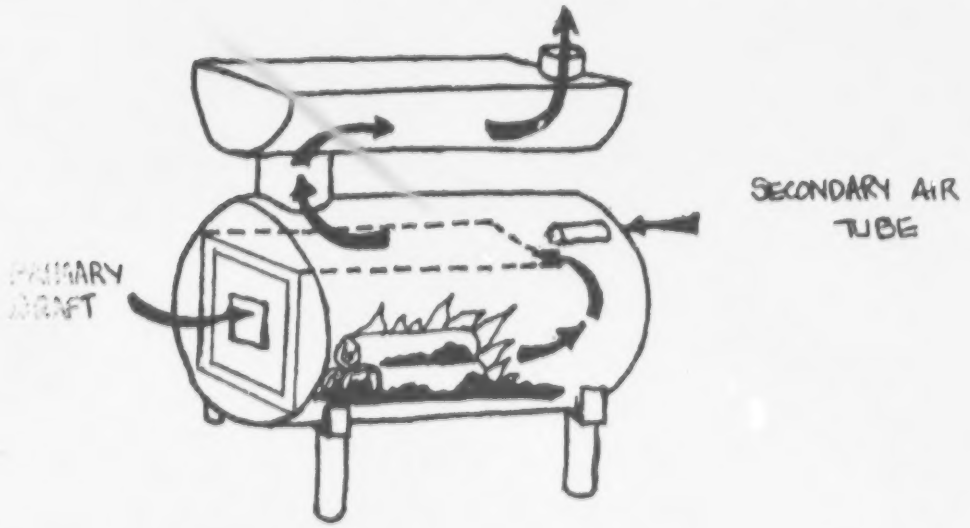
The front end combustion stove takes advantage of a baffle system to keep the heated air in the stove longer. The baffle also limits combustion to only one portion of the fuel supply. This causes the wood to burn in a limited region but at a higher temperature, reducing creosote production. Another function of the baffle is to force the unburned gases back over the hottest part of the fire.

DIAGRAM F



In the Sevca stove, the volatiles are passed over the fire and are heated before being ignited when secondary air is provided. The secondary draft is located in the back of the stove. Heat from both combustion processes passes into an upper chamber which absorbs and radiates heat from the flue gases into the room. See Diagram E.

DIAGRAM G



Two design features make this stove very efficient; 1) the combination of an internal baffle and a secondary air intake in the lower chamber and 2) the heat exchange unit in the top. The stove's inexpensive construction from LP gas cylinders also adds to its attractiveness for the average homeowner.

Open fireplaces are inefficient because there is no means of controlling the amount of air that escapes up the flue. The heated volatile gases are carried out the chimney before they are completely consumed. In addition, warm air from the room is drawn up the chimney both when the fire is just starting and when it is dying out, making the net energy effect close to zero.

For houses with room partitions, furnaces make sense. A furnace located in the basement of a house means less soot, bark and sawdust in the house. In general, large wood can be used, making it less work to prepare wood for a fire that will be longer burning. The fire can be bigger and hotter than single fires in each room and can therefore burn more efficiently. The chief differences between furnaces lie in 1) the firebox materials, 2) dimensions of the heat exchange area, 3) exhaust flue patterns and 4) draft controls. There are wood furnaces on the market today with thermostatically controlled oil burners attached to or integrated with wood burning sections.

Stoves and furnaces are made from cast iron, sheet steel, or some combination of the two. There are differences between cast iron and steel even though these metals have the same thermal conductivity. When a thin steel stove cools down, the lowered temperature is immediately reflected in the temperature of the room.

In general, cast iron stoves have thicker walls, store more thermal energy and therefore radiate more heat after the fire has gone out. The heat retaining characteristics of cast iron means that a higher temperature can be maintained

in the fire box for better consumption of gases with less air intake than is required in a thin steel stove. Sheet metal stoves compensate for this deficiency by using firebrick. The firebrick increases the fire box temperature and protects the steel from warping and burning out. Sheet metal stoves are usually less expensive but do not last as long. Most American stove manufacturer use sheet steel construction because high quality cast iron is both expensive and difficult to obtain.

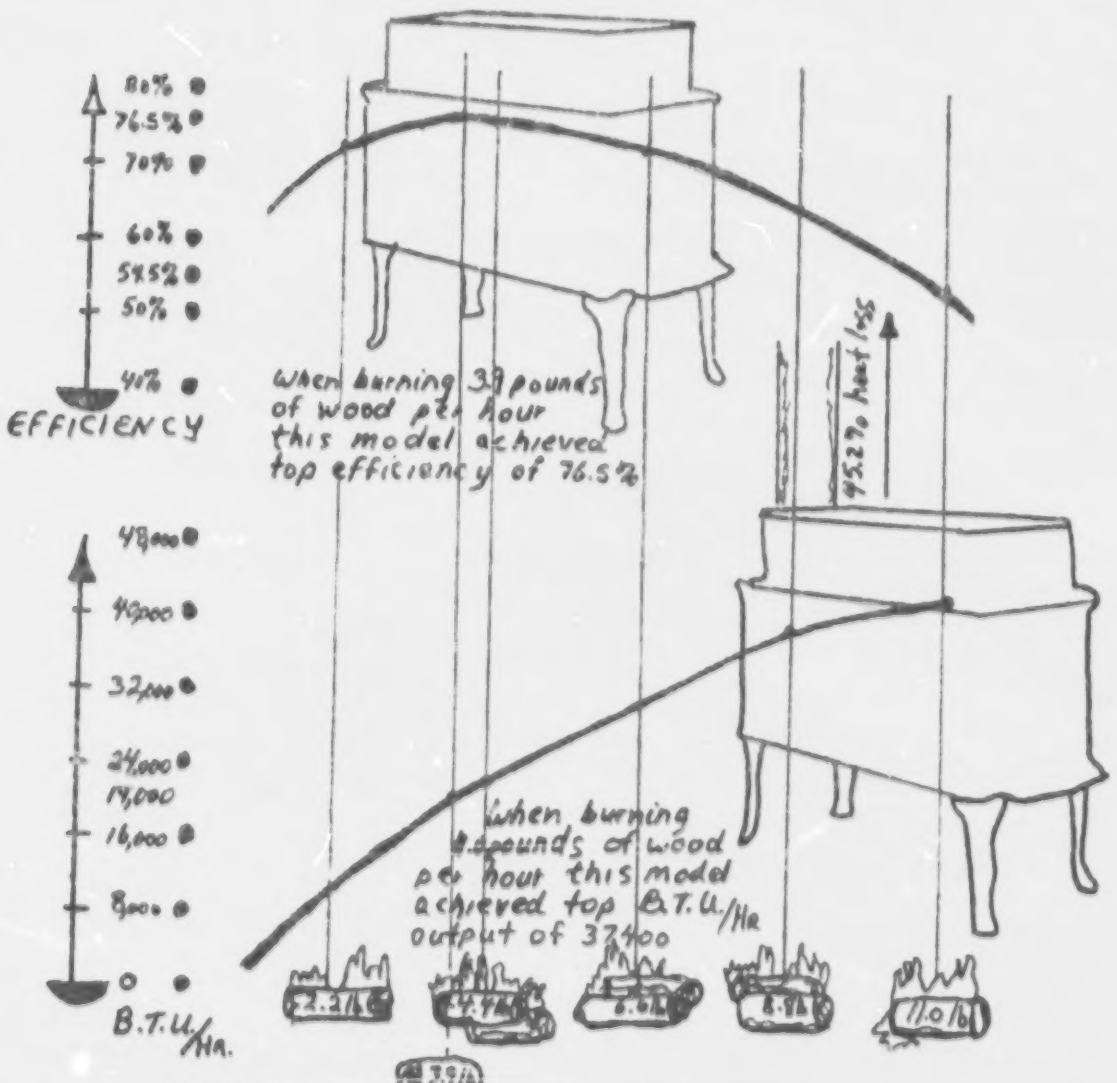
Heat transfer from the stove pipe is important to the total heating effect. A four by six foot stove pipe can contribute 15 to 25% of the total useful heat. However, a long stove pipe can create draft proplems and creosote buildup.

Draft depends on three things: differences of temperature between outside air and flue gases (ΔT), height of the flue, and amount of friction in the chimney (size of the opening). Anyone of these variables can be a limiting factor. A heat exchanger added to a stove pipe will cut draft considerably when in operation because the buoyancy of the gases decreases as the temperature is lowered. Larger flue openings are required for open stoves such as Franklin fireplaces because the flue gas is diluted by excess room air.

Stove ratings expressed in terms of number of rooms or cubic feet of volume that can be heated are meaningless. The surface area of walls, the degree of insulation, the amount of infiltration in the room, the room contents, the difference between the indoor and outdoor temperatures all affect the ability of a stove to heat a given living space. Rating a stove in terms of BTU/hr is also misleading. BTU output depends on all the factors that affect efficiency. Wood stove efficiency is difficult to assess when flue drafts vary from one chimney to the next, when moisture content varies from green to air dried,

and when size of wood varies from large chunks to wood shavings. Differences in manual operation of stoves also change efficiency. A stove when operated to warm the blood of Sam Magee will have a different efficiency from one when it is dampered down to smolder like burning leaves. Standardized testing of time periods over which each of several heat outputs can be maintained between fuel loadings and the energy efficiencies at each output are necessary to determine energy efficiency and ease of operation. The following is an efficiency graph for a scandenavian air tight stove that has been tested in this fashion:

Testing Results on No. 118 Jotul



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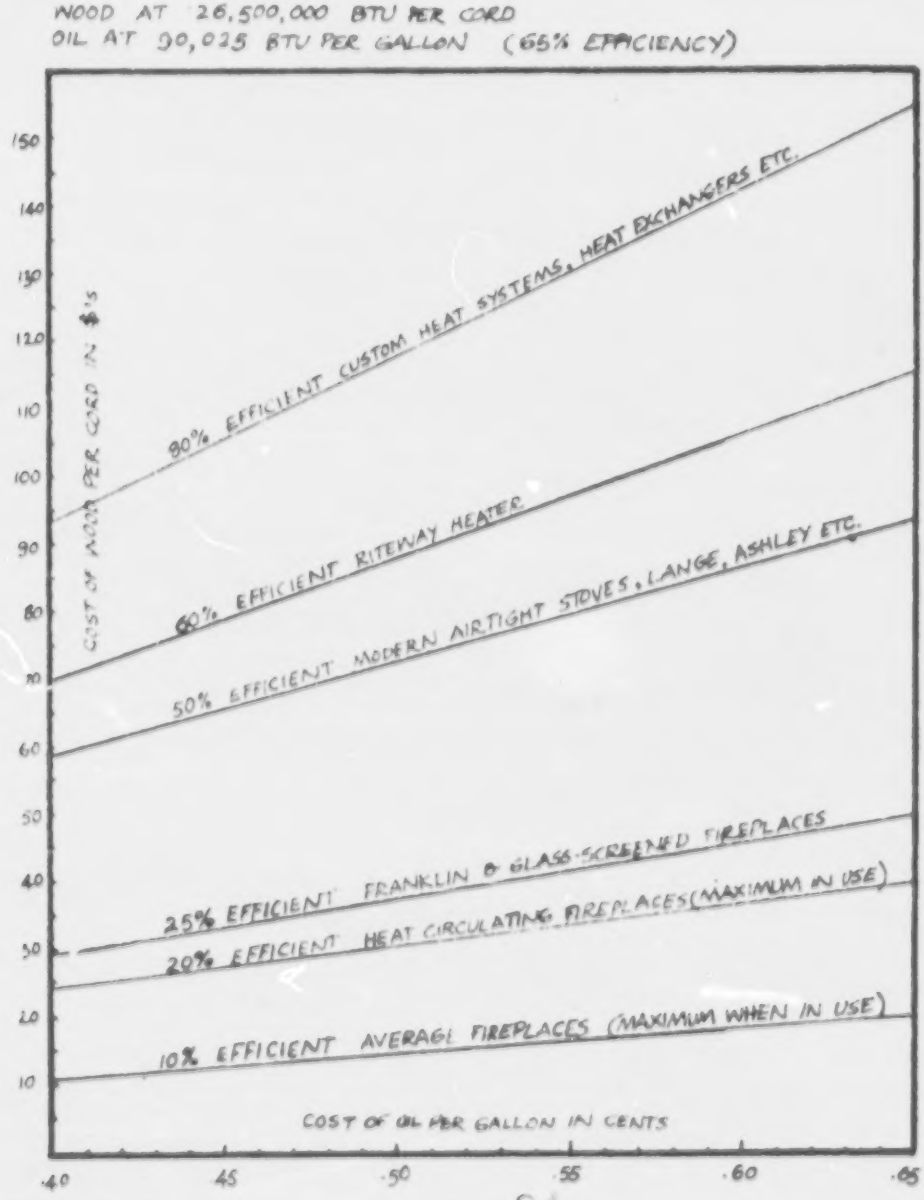
The top efficiency of 76% was achieved when 3.1 lbs/hr were burned. If the draft is reduced so that less wood per hour is burned, more volatile gases escape up the chimney and the efficiency goes down. At the other extreme, burning more than 3.1 lbs/hr lowers the efficiency even though more of the volatile gases are burned because more heat is escaping up the chimney. The bottom graph shows that the maximum BTU output occurs at 11 lbs/hr.

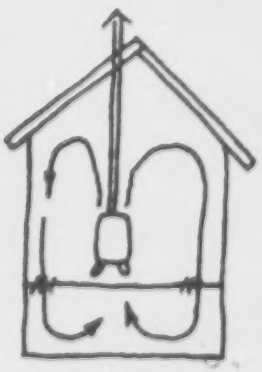
The following graph from Woodburning Stoves by Bob and Carol Ross shows the cost of air dried hardwood per cord equivalent to a range of fuel oil prices at various stove efficiencies.

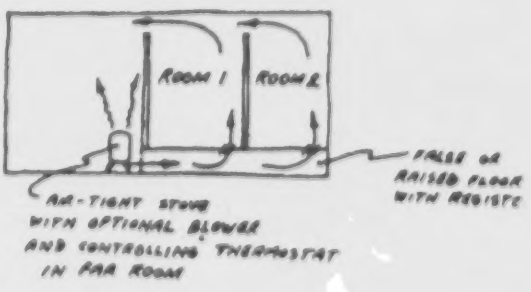


Keep in mind that the efficiencies cited are average figures and depend on the many variables cited above.

Sizing a stove for the space that is to be heated is important! If the stove's heating capacity is too great for the room the damper will have to be nearly closed resulting in a less efficient burn. At the other extreme, if the room is too large for the stove, a rapid, high temperature, less efficient burn is necessary to maintain a comfortable temperature. Thermostatically controlled airtight stoves placed in rooms too small for their size will heat up rapidly causing the thermostat to shut off and the fire to smolder. Bigger is not always better when it comes to wood stoves!

A correct balance between stove energy output and the house heating requirement is necessary. The conservation packet shows how to calculate heating requirements for a dwelling. The effectiveness of a given wood stove in heating a dwelling also depends upon heat transfer by convection and radiation. Radiant energy, effective only in areas within view of the stove, decreases as the distan from a stove increases. Convection requires the free movement of air from the stove to various parts of the house. The following diagram shows convection patt around a stove heating a single room. Stoves will not heat more than one room unless there is free air movement between the rooms. Large openings between rooms and floor and wall registers are used to increase air movement. The rate of natural convection is governed by the difference in temperature between stove sides and the air in the room, height of the room to be heated, and the freedom of air movement.




ROOM 1
ROOM 2
FALSE or RAISED FLOOR WITH REGISTE
AIR-TIGHT STOVE WITH OPTIONAL BLOWER AND CONTROLLING THERMOSTAT IN ONE ROOM

WOOD STOVE ACTIVITIES

Activity #I WOOD STOVE FREEBEES

There is no consumer guide as yet for wood burning stoves. Variety of stove design, flue diameter, chimney draft, size, type, and dryness of wood, as well as differences in operating techniques make efficiency figures difficult to obtain. Write the following manufacturers of stoves for their descriptive information:

ASHLEY

Martin Industries
1064 17th Ave. S. W.
P.O. Box 730
Sheffield, Alabama 35660

BETTER N BENS

C & D Dist., Inc.
P. O. Box 776
Old Saybrook, Conn. 06475

DEFIANT STOVES

Vermont Castings, Inc.
Prince Street
Randolph, Vt. 05060

DOVER

Dover Stove Co.
Main Street
Sangerville, Me. 04479

Oakwood Co.
Route 226
Chelsea, Me.

FRANKLIN
QUEEN ATLANTIC

Portland Stoves Foundry, Inc.
57 Kennebec St.
Portland, Maine 04104

JOTUL

Kristia Associates
449 Forest Avenue
Portland, Maine

LANGE

Scandinavian Stoves, Inc.
Box 72
Alstead, N. H. 03602

MORSO

Southport Stoves
Division of Howell Corp.
1180 Stratford Rd.
Stratford, Conn. 06497

RITEWAY

Riteway Mfg. Co.
Marco Industries, Inc.
Harrisburg, Va. 22801

RITEWAY

Allan Johnson
Box 128
East Holden, Me. 0442

RAM FORGE

Milton Hills
Belfast
Maine 04915

SHENANDOAH

Shenandoah Mfg. Co.Inc
P.O. Box 839
Harrisburg, VA. 22801

SUNSHINE

Sunshine Stove Works
Norridgewock
Maine 04957

TEMPWOOD

Mohawk Industries, Inc
173 Howland Ave.
Adams, Mass. 01220

TROLLA

Lyons Supply
Manchester, N. H. 031

Does it make sense to compare the stoves on a cost per wood volume or a cost weight basis? How could you determine BTU output/hr for the various stoves? Which stove has the best guarantee on workmanship and materials? Rate the stoves from 1 to 10 in cost. How does the cost compare to oil heating units?

Looks have nothing to do with efficiency. Visually pleasing designs however do increase marketability of stoves and increase public acceptance of wood as a fuel. In your eyes, which stove would win Miss Wood Stove USA? Which would win the Jolly Wopper Award for displeasing appearance?

Activity #2 STOVE DESIGN

Maine homeowners are turning to wood for heat as the price of #2 heating oil goes up. Problems have arisen, however, in the transition from oil heat to wood heat due to the lack of homeowner experience with the convenient and safe methods of cutting, splitting and burning wood. In this activity, you will be thinking of ways to improve stove efficiency, wood burning convenience and stove safety.

Part 1 - Stove Design

Design, using proper drafting techniques, a wood burning stove that incorporates the following features:

a) inexpensive materials
b) ease of construction
c) durability
d) heat output control
e) minimum creosote buildup in flue
f) ease of operation
g) beauty
h) safety in operation
i) efficiency

Make a drawing of your design. Outline how your stove satisfies each of these design features. List construction materials and their cost. List construction procedure.

Part II - Wood Burning Convenience

List ten ways to make wood heat more convenient. (i. e., decrease the number of times the wood is handled, combine storage and drying facilities) List and describe specific tools and facilities that would make the handling and burning of wood easier. (i. e., house modifications such as enlarged basement openings, attached wood sheds, etc.) Draw, using proper drafting techniques, three of your ideas.

Part III - Safety

Insurance rates for homeowners who burn wood in space heaters are higher than for homeowners who burn oil. The higher rates are in part due to the number of improperly installed and poorly operated stoves which cause house fires. Call your local fire inspector and find out what safety precautions are necessary for installing and operating a wood stove. List ten safety considerations for

wood space heaters. (i. e., minimum distance from walls, fireproof mats under stove, etc.) List five operating procedures which increase wood stove safety. What type and size fire extinguisher(s) are necessary for an average size house? Where should they be located in the house? How much do smoke detectors cost? Where can they be purchased? How and where should they be installed?

Activity #3 WOOD HEAT AND HOUSE DESIGN

Energy generated by the combustion of wood in a space heater is transferred to its surroundings by three energy pathways: conduction, convection and radiation. Conduction is the transfer of heat energy via molecular vibration through a substance. Heat generated in the firebox of a stove passes through the stove's walls in this fashion. Air passing over the stove's sides is heated and rises, creating air currents which move this heated air to cooler areas of the room. This method of heat transfer is called convection. Radiation is the transfer of energy by electromagnetic waves traveling at the speed of light. Energy in this form is converted to heat when it touches your skin. The ability of a stove to heat a living space is determined by the ease with which these heat transfer mechanisms are allowed to work.

Heat conduction through a stove wall is governed by the thickness of the stove wall material as well as the material's thermal conductivity. Light gauge sheet steel stoves conduct heat rapidly to the exterior surfaces where it is quickly radiated and convected into the surrounding air.

The amount of energy stored in a stove depends on the specific heat of the stove's walls and the stove's mass. The specific heat is the amount of heat energy that can be stored per pound of a substance per degree F rise in temperature. This is referred to as thermal mass and can be calculated for any given material by multiplying the stove's mass or weight by its specific heat. Because there is little energy storage in a light stove, the stove stops providing heat to the room once the fire is out. Heavy cast iron stoves, on the other hand, store a certain amount of heat in their thicker walls and give off this heat gradually after the fire has gone out.

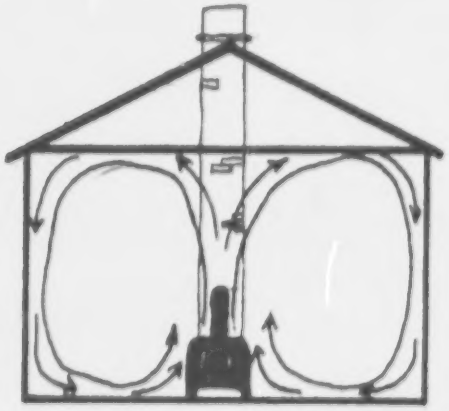
Massive materials such as stone, masonry and water can absorb heat from a stove in operation and radiate this heat energy into the living space after the fire is out much like a heavy cast iron stove does. Masonry walls, steel water containers, or rocks located behind stoves are used in some houses for this purpose. Chimneys and cement hearths within the house help to store energy. The Maine Audubon uses 100 tons of crushed rock in its new building to store heat from a forced air wood furnace. Fans located over the exhaust flue blow heated air into the rock storage bed. Each degree rise in temperature of the rock bed represents 40,000 BTU of heat energy.

Projects:

A. Design and build a model of a means of heat storage for a wood stove that could be installed in an existing home in Maine.

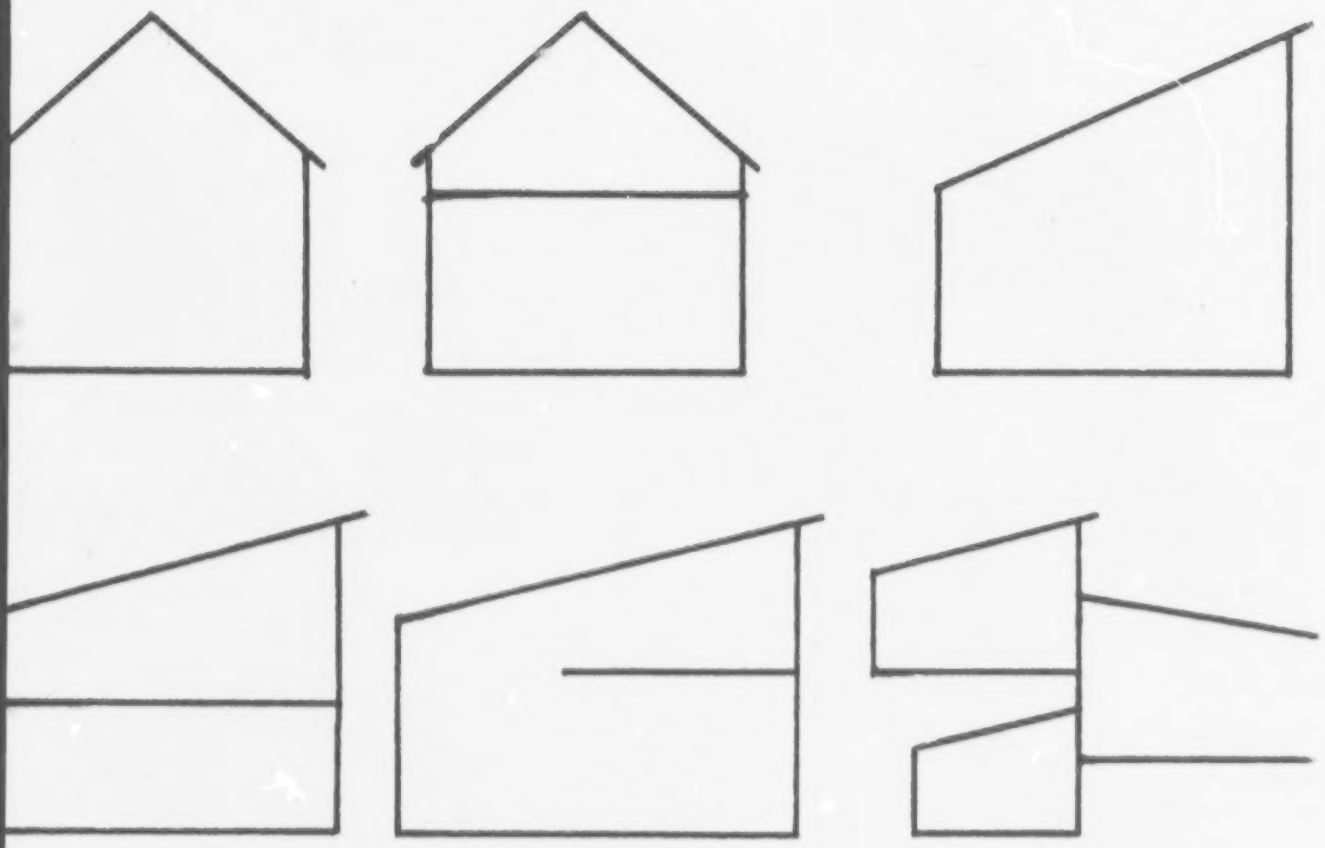
B. Design a means of heat storage that could be incorporated into a new fireplace.

Convection of heated air from a stove to cooler areas of a house can be facilitated in a number of ways. Natural convection around a wood stove begins when air in contact with the hot stove surface is heated and rises. At the ceiling, it is channelled outward toward the walls and then downward toward the floor. As the air flows downward, it looses heat to walls and windows At floor level, this cooler air is drawn toward the stove and is reheated. See diagram below:



Placing the stove in the center of the room and keeping the airflow paths free of furniture aides in this natural convection. Large door openings and large outlet and return registers between rooms also aid in the free movement of air. Fans are necessary for air movement between rooms with narrow doors or to increase convection in larger rooms. Stairways and ceiling registers act to circulate air between floors.

C. Where in each of the following houses would you place a wood stove to most uniformly heat the whole house?



D. Design a home that can be heated entirely with one wood stove.

E. List five modifications of an older home that would facilitate its heating with one or two wood stoves. Draw plans, list materials, and costs for each modification.

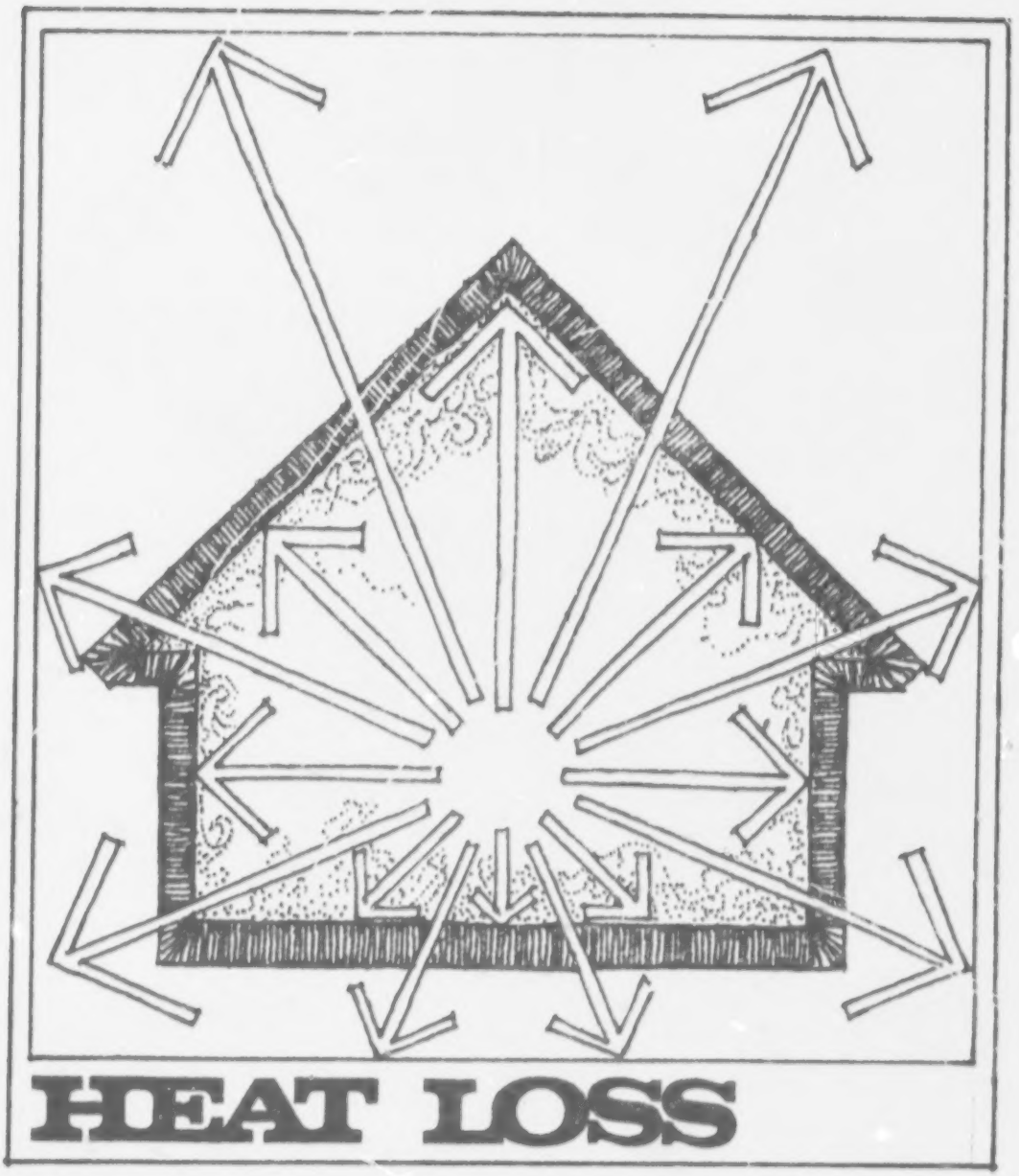
Radiation from a wood stove only strikes objects directly in sight of the stove (Why?). Reflective foil can be used to redirect radiation from stoves or stove pipes into the room.

F. Hold a piece of reflective foil next to your cheek. What happens? Line a fireplace with aluminum foil. After lighting a fire in the fireplace, do you notice any difference in its heat output?

G. Suggest five uses for foil that would increase the ability of a stove to heat a room. List five uses of foil that would help conserve energy in your family's house. (i.,e., placing foil behind radiators)

Activity #4 ECONOMICS OF WOOD HEAT

Calculate the BTU/hr necessary to heat the industrial arts shop using information in the Conservation packets. What weight and volume of air dryed white birch would be necessary to heat this space assuming that you were using a wood furnace that was 75% efficient. If the cost of birch were $50/cord delivered and oil is $.45/gal., which would be cheaper, oil or wood? Assume the oil burners have an efficiency of 75%.


HEAT LOSS

HEAT LOSS

FOR: Physics, Mathematics and Science Teachers

INTRODUCTION:

About 20% of the total energy consumed in the United States is used in heating buildings. Since there are no products manufactured and no useful work performed directly by this energy, it is, in the end, a total waste. Of course, living space must be heated for comfort in the winter, but the amount of energy required can be greatly reduced by proper energy conserving building techniques. This packet describes ways in which heat is lost from a building and techniques for reducing losses.

PRINCIPLES: Conservation of energy
Conduction
Radiation
Convection

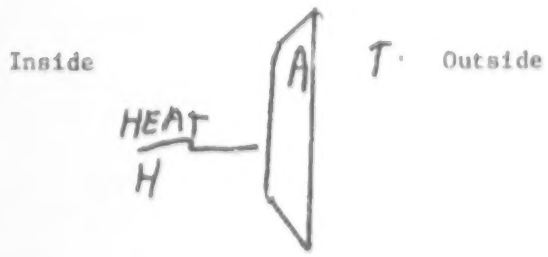
QUESTION: How would it be possible to heat a house by burning only 2 cords of wood per winter?

HEAT FLOW

The basic equation used in calculating the flow of heat through a surface is: (Fig. 1)

$$H = \frac{A \Delta T}{R}$$

FIGURE #1



Where H = rate of energy flow through area A in $\frac{BTU}{HR}$

A = area of surface losing heat is Sq. Ft.

Δ T = difference in temp., T inside - T outside, F^{O}

R = "thermal resistance" $\frac{Sq.\ Ft.,\ F^{O}}{BTU}$

Actually, heat flow through any ordinary material is exceedingly complicated, consisting of four different physical mechanisms:

a) Conduction
b) Radiation
c) Convection
d) Infiltration

A. Conduction is the mechanism by which the handle of the frying pan gets hot. Heat energy consists of energy of motion (kinetic energy) of the atoms and molecules of a substance. In conduction, the atoms and molecules stay in one place but transfer their heat energy by "bumping" their neighbors. Therefore, conduction is a large contributor to heat flow in solids.

B. Radiation is the mechanism by which the energy of the sun is transferred 93,000,000 miles through space to the earth. Warm objects radiate heat energy in the form of electromagnetic radiation in exactly the same way that a light bulb radiates light. Heat radiation has wave lengths longer than visible radiation, the longest wave length of which corresponds to red. It is, therefore, known as infrared radiation. Our eyes tell us that mirrors, metallic foil and white surfaces reflect nearly 100% of the visible radiation which strikes them. The same is more or less true of infrared radiation, although metallic foils are by far the best reflectors of heat.

C. Convection is the mechanism by which a furnace heats a house. The heat energy of the atoms and molecules is transferred by actual motion of a fluid material. Warmer (and therefore lighter) fluids tend to rise under the influence of gravity. Systems utilizing this natural phenomenon are known as natural or gravity convection systems. Air ducts in upper story floors use this phenomenon to pass the warmer, lighter air up from below. Systems in which the natural convection is boosted (or even reversed) by pumps or fans are known as forced hot air systems. Convection occurs naturally in heating systems but also within floor, wall and ceiling cavities, transferring house heat from warm inside surfaces to cold outside surfaces.

D. Infiltration is a special case of convection. It is the physical exchange of inside and outside air which occurs primarily around doors and windows. Since air from outside must be warmed to the average inside temperature, infiltration is a source of heat loss. The equation is:

$$H_{Infiltration} = 0.018\ Q\Delta T$$

Where H = heat in BTU/hr

Q = cubic feet of air infiltration per hour

Δ T = temperature difference in ^{o}F, inside minus outs

Infiltration is difficult to measure in a poorly constructed house. As an average figure for an old house before installation of weather stripping and storm windows and doors, assume the contained air is exchanged four times per hour. A new house can be constructed carefully enough to limit infiltration to virtually any number of hourly air changes desired. However, for health,

it is recommended that the contained air be exchanged at the rate of at least once per two hours.

QUESTION: Why is it that Eskimo children can romp naked in their igloos without feeling cold?

THERMAL RESISTANCE, R

Fortunately, we don't need to calculate the exact equation of heat flow for all three mechanisms in any real instance. Heating engineers have conducted experiments with all the common building materials in many different configurations and measured the effective thermal resistances, R. Some of their results are tabulated in Tables I, II and III. Using these tables, we can quickly calculate the total thermal resistance of any construction and calculate the resulting heat loss by the equation in Figure #I.

TABLE #I

THERMAL RESISTANCE, R, OF SURFACES

SURFACE	METALLIC FOIL	PAINTED WHITE	DARK ORDINARY MATERIALS
Inside Wall	1.7	1.3	0.7
Inside Ceiling	1.3	1.1	0.6
Inside Floor	4.5	2.7	0.9
Outside Surface	0.3	0.2	0.2

TABLE #2

THERMAL RESISTANCE, R, OF AIR SPACES

AIR SPACE	DIR. OF HEAT FLOW	THICKNESS (inches)	SURFACES METALLIC OR FOIL	PAINTED WHITE	DARK MATERIAL
Horizontal Ceiling	Upward	3/4"	1.7	1.4	0.8
		4"	2.1	1.6	0.9
Horizontal Floor	Downward	3/4"	3.6	2.4	1.0
		4"	8.9	4.0	1.2
Vertical Wall	Horizontal	3/4"	2.8	2.0	1.0
		4"	2.6	1.9	0.9
Pitched Roof	Upward	3/4"	1.9	1.5	0.8
		4"	2.2	1.7	0.9

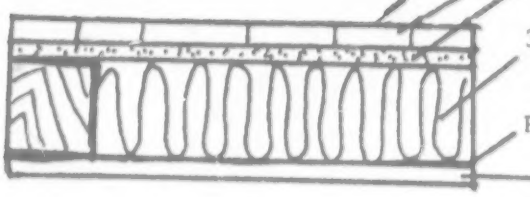
TABLE #III

THERMAL RESISTANCE, R, OF BUILDING MATERIALS

MATERIAL	R (per inch thickness)	R (total)
Softwood	1.25	
Hardwood	0.91	
Plywood	1.25	
Poly Vapor Barrier	----	0.00
Gypsum Board	0.90	
Concrete	0.08	
Stone	0.08	
Brick, Plaster	0.20	
8" Concrete Block	----	1.11
Cork	3.50	
Carpet & rubber pad	----	1.20
Carpet & Fiber pad	----	2.10
Asphalt roofing	----	0.40
Window		
Single pane	----	1.0
Double pane	----	1.5-2.0
Door		
Single wood	----	2.0
With storm	----	3.0
Fiberglas batt	3.33	
Cellulose	3.5	
Polyurethane	6.5	
"Styrofoam"	5.5	
Urea Formaldehyde	4.7	
Snow (Igloo Material)	1.0	

FIGURE 2

TYPICAL WALL



	R
Outside Surface	0.2
1" Pine Board	1.2
3/8" Plywood	0.5
3 1/2" Fiberglas	11.0
Poly Vapor Barrier	0.0
1/2" Gypsum Board	0.5
Inside Surface, White	1.3
TOTAL R =	14.7

Figure 2 shows such a calculation for a typical wood frame wall. For example, assume a wall 10' high X 40' long of the construction shown in Figure 2. When the temperature inside is $70^{\circ}F$ and the temperature outside is $20^{\circ}F$, how many BTU's per hour are being lost through the wall?

$$H = \frac{A \Delta T}{R}$$

$$= \frac{10' \times 40' \times (70-20)F^{\circ}}{14.7 \text{ Sq. Ft. } F^{\circ} \text{ BTU}}$$

$$= 1{,}360 \text{ BTU/Hr}$$

The entire surface of a house consists of an assemblage of such surfaces, each having a different thermal resistance R and area A. The total rate of heat loss is the sum of the heat losses of all of the parts.

Losses = Loss through roof + walls + floor + doors + windows + infiltration
(Sum of)

ANNUAL HEAT LOAD and DEGREE DAYS

H, the rate of heat flow calculated above, gave us the heat loss in 1 hour at a certain difference of temperature, ΔT. Obviously, from the equation, a doubling of ΔT doubles H. Heating engineers have found that they can predict the heat loss of a building using the quantity DEGREE DAYS, DD:

DEGREE DAYS PER DAY = $(65^{\circ}F$ - T Average)

That is, the number of DD in one day is $65^{\circ}F$ minus the average temperature for that day when T Average is exactly halfway between the highest and lowest temperature of the day. It is assumed that domestic heat sources within the structure contribute enough heat so that the heating system will not be required to supply heat until the average outside temperature drops to $65^{\circ}F$.

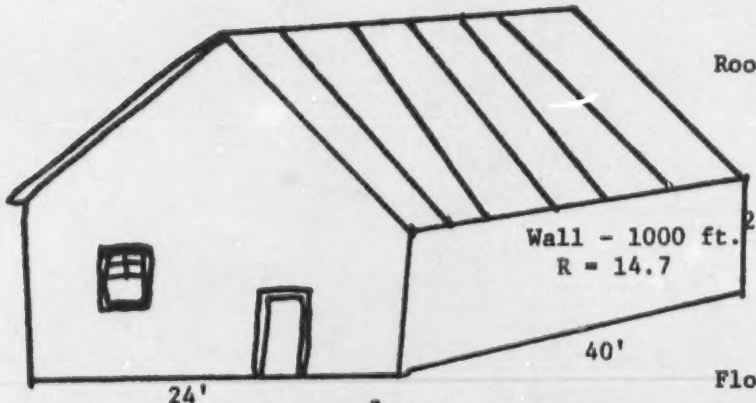
Instead of calculating the heat loss of a house hour by hour throughout the year and taking the sum, we now have one very simple calculation:

$$H \text{ Annual} = 24 \times DD \times \underset{\text{Through Surfaces}}{\text{Sum}} \left(\frac{A}{R}\right) + \underset{\text{Infiltration}}{0.43 \, Q \times DD}$$

EXAMPLE

Let's calculate both the hourly and annual heat loads of the house shown in Figure #3. Typical R values for the different surfaces are listed. For Portland, Maine, the Design Δ T (largest Δ T expected in an average heating season) is 80 F^{o} and DD = 7,680.

FIGURE #3



MAX Δ T = 80^{o}F
DD = 7,680
Volume = 11,500 cubic ft.
1 air change per hour

TABLE #IV

SURFACE	R	AREA (S.F.)	DESIGN T, F^{o}	$H_{Max} = \frac{A\,T}{R}$	$H_{Annual} = 24\ DD \times \frac{A}{R}$
Floor	10.0	960	80	7680 BTU/HR	177 X 105 BTU
Wall	14.7	1000	"	5440	125 " " "
Roof	14.0	1040	"	5940	137 " " "
Window	1.5	180	"	9600	221 " " "
Door	2.0	40	"	1600	37 " " "
Infiltration	Q = 11,500 cu. ft./hr			16,560 BTU/HR	380 " " BTU

H_{Max} = 46,820 $\frac{BTU}{HR}$; H_{Annual} = 1,077 X 10^{5} BTU/YR

To put the results into perspective: 1) Most oil furnaces are designed to produce 100-150,000 BTU/HR while burning. It is therefore obvious that the smallest oil burner available will run only about 50% of the time even on the coldest night of the winter. Wood stoves are designed to produce heat in the range of 5,000-50,000 BTU/HR. Therefore, one large wood stove will easily heat the example home. Note, however, that at minimum output, the temperature of the house will be raised a minimum of 10°F above the outside temperature. Since wood stoves are either "on" or "off", the user must accept extremely rough temperature parameters, (i.e. no thermodynamic fine tuning of a wood stove is possible). 2) One gallon of heating oil contains a potential of 140,000 BTU. Burned at an average furnace efficiency of 70%, it yields 100,000 BTU/gal of heat to the house. Heating engineers have defined a quantity of heat roughly equivalent to a gallon of oil as the "Therm" (1 Therm = 100,000 BTU). 3) One cord of dry hardwood yields, after burning in a good stove, about the same amount of heat as 200 gallons of oil.

A large percentage of homes in Maine have no insulation. At the other extreme, new energy standards are calling for 6" of Fiberglas in the walls, 12" in the roof and insulating drapes or shutters over windows at night. Let's compare the houses:

House 1: Old, uninsulated, no storm windows or doors, infiltration of 4 air exchanges per hour.

House 2: The present industry standard house shown in the above example.

House 3: Increased insulation to R20 floor, R24 walls, R38 roof, storm doors and windows, R5 night window covers, and infiltration of 1/2 air exchange per hour.

TABLE #V

SURFACE	AREA	DESIGN ΔT	R			H_{Max}, BTU/HR			H_{Annual}, 10^5 BTU/YR		
			House #1	#II	#III	#1	#II	#III	#I	#II	#III
Floor	960 S. F.	80F°	10	10	20	7680	7,680	3,840	177	177	89
Wall	1000	80	3.7	14.7	24	21,620	5,440	3,330	498	125	77
Roof	1040	80	3.0	14.0	38	27,730	5,940	2,190	639	137	50
Window	180	80	1.0	1.5	6.5	14,400	9,600	2,220	332	221	51
Door	40	80	2.0	2.0	3.0	1,600	1,600	1,070	37	37	25
Infiltration						66,240	16,560	8,280	1,520	380	190
Totals						139,270	46,820	20,930	3,203	1,077	482

FACTORS OTHER THAN INSULATION R-VALUE

Infiltration: We have seen that it is possible to reduce infiltration to nearly any low level we wish. In other words, we can control air exchange. We label unwanted air exchange as "infiltration" but call desirable air exchange "ventilation". Ventilation is required in order to replace "stuffy" air. Factors influencing stuffiness include: number of inhabitants, volume of air in house, type of food cooked, cleanliness of people and clothing, smoking, amount and type of house plants.

Solar Orientation: Solar radiation through windows adds heat to a house. At the same time, as we have seen above, heat is being lost through the same windows by conduction. Depending on the intensity of radiation, solar orientation, number of glazings of the windows, and outside versus inside temperatures, windows may cause either a net gain or a net loss of heat. Calculations show that double glazed windows (either thermopane of single glass plus storm window) in Portland, Maine show the following heat balance for the heating season: (Table VI)

TABLE #VI

WINDOW ORIENTATION	HEAT BALANCE
NW, N, NE	Net Loss
E, W	Break Even
SE, S, SW	Net Gain

Exposure: Exposure to wind hurts in two ways. Infiltration around windows and doors is largely the result of wind pressure. Reducing the wind velocity around a house will dramatically reduce infiltration in a poorly constructed or older non-weather stripped house. In a tight, well-constructed house, infiltration is already below ventilation requirements and so wind has little effect. However, we are all aware of the windchill effect. Heat is lost through the skin by conduction, convection, radiation and evaporation. Both convection and evaporation are functions of air speed over the skin. A certain temperature with wind is equivalent to a much lower air temperature with no wind. The severity of winter is subjectively associated with the discomfort of being outside.

Effective Temperature: Because the body exchanges heat with its surroundings by radiation as well as by conduction and convection, the effective temperature of a space defined by bodily comfort is not necessarily shown by the thermostat. The effective temperature of an enclosed space is the average between the air temperature (shown by the thermometer) and the temperature of the surrounding surfaces. If a house were perfectly insulated, the temperature of the inside wall, floor and ceiling would be identical to the air temperature. In a poorly insulated house, the surfaces may be dramatically lower. This is particularly

true of windows. The discomfort of sitting next to a sliding glass door on a cold winter night is due not only to cold drafts but also to the fact that your body is radiating heat to a surface at only 30-40°F! Just the opposite happens with a wood stove. An air temperature of 60°F is quite pleasant when sitting next to a wood stove with a surface temperature of 200°F.

Surfaces which reflect radiant energy produce an interesting effect. When you look into a mirror you see your image because the mirror reflects visible radiation. When you stand in front of an infrared reflector (such as aluminum foil) you feel your thermal image! If you stand between a hot stove and a sheet of aluminum foil you feel almost as if you were standing between two stoves! Metallic foil placed over cold windows at night increases their apparent radiant temperature to nearly the average of the rest of the room because they are merely reflecting the thermal image of the other room surfaces.

QUESTIONS AND ACTIVITIES

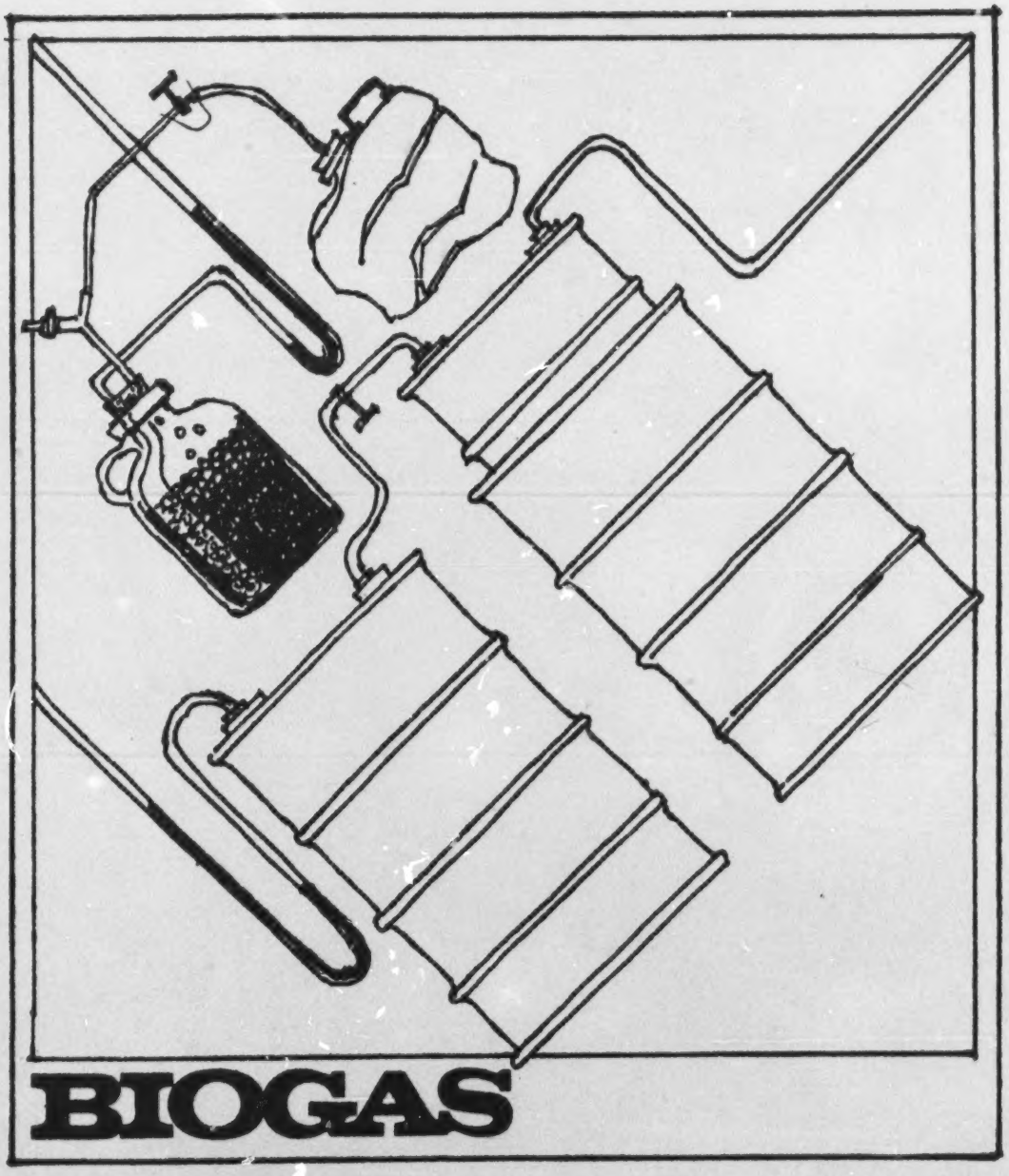
1. Compute the annual heat losses for your own house by the method shown in the text. If your house is not already insulated to the equivalent of 6" of Fiberglas in walls and floor and 12" in the ceiling, compute the heat savings from such improvements. Last, calculate on the basis of material cost and the value of fuel saved, the payback period (the number of years for savings to equal cost).

2. Assuming one degree day is saved for each degree the thermostat is lowered during the heating season (assume 180 days), by what percentage is the annual fuel bill lowered in Portland, Maine, (7680 DD) by lowering the thermostat from 75° to 68°F?

3. Using Table #III, construct a new table showing the number of inches of thickness of various materials required to achieve the same thermal resistance as 3 and 1/2 " of urethane foam. A) Why are more and more people installing plastic foams in their walls in spite of their relatively high cost? B) How well insulated are houses with 24" stone walls; with 8" log walls?

4. A backyard inventor has prepared a year-round snow chest food cooler. In the winter he shovels snow from the roof into a large insulated box within which he places a small cooler box. Assuming the inside of the snow chest is a cube 8' on a side, that it has been packed with snow having a density 1/3 that of water, that the thermal resistance os the walls is equivalent to 4" of styrofoam, and that the inside box is of negligible size and never opened, for how many days will the inside temperature remain at 32°F if the outside temperature remains at an average of 60°F?

5. Obtain a piece of "builders foil" (highly reflective kraft paper backed aluminum foil similar to that used on fiberglas insulation). Hold it several inches from your face so that it covers one cheek but not the other. Which side of your face feels warmer? The demonstration is more effective when the air temperature is low, such as outside in winter. Why? Why are motorcyclists gloves aluminum colored? Why are astronaut suits made of reflective aluminum fabric?


BIOGAS

BIO-GAS INTRODUCTION

Bio-gas is the term used to denote the mixture of gases produced by anaerobic decomposition of organic materials. The major portion of this gas is CH_4, or methane, the primary component of natural gas. Natural gas used in this country yeilds between 1100 and 1200 BTU's/ft^3. Bio-gas yeilds between 600 and 700 BTU's ft^3. The reason for the difference in energy content is that natural gas is about 80% methane, while bio-gas averages about 54-70% methane, remaining gases being carbon dioxide, hydrogen, and nitrogen with traces of carbon monoxide, oxygen, and hydrogen sulfide. 225 ft^3 of bio-gas equals a gallon gasoline in BTU value. The per capita consumption of natural gas per day in the U.S. is about 350 ft^3. If we can economically produce bio-gas, we can use it as we use natural gas now.

TABLE 1
COMPARED ENERGY VALUES OF DIFFERENT KINDS OF GAS

natural gas (in USA)	1100-1200	BTU's per ft^3
pure methane	1011	"
ideal digestor gas	1000	"
low quality "	650	"
coal gas	450	"

As a source of power, bio-gas has a unique set of advantages and disadvantages. On the positive side, bio-gas is a renewable resource, being the end product of the life cycle of manures and vegetable wastes. The process of producing it is "natural". Pratically all the work is done by nature. Not only usable gas is produced by this process, but also an organic fertilizer, considerably higher in nitrogen than any form of animal waste. On the negative side, methane is extremely hard to compress, which tends to rule it out as a fuel for automobiles and other mobile gas users. It is the lightest of the hydrocarbons and must be compressed to 3000 pounds for easy transport. To operate a single family digestor, a person must spend a portion of each day carrying out repetitive and often laborious tasks.

Lastly, there must be a constant supply of vegetation and animal waste to feed the digestor. On a farm, this would be no problem. In fact, it would be a very good way to take care of such wastes.

TABLE 2
FUEL VALUE OF AVAILABLE ORGANIC WASTES IN THE UNITED STATES

Organic wastes in U.S./year	.2 billion tons(wet weight) 800 million tons(dry weight)
Dry organic wastes easily collectable	136.3 million tons
Methane available from dry wastes	1.36 trillion ft^3/year
Fuel value of collectable methane	1,360 trillion BTU's/yr

1360 trillion BTU's/year represents 150% of the gasoline energy used by all U.S. farm equipment, 7% of the total natural gas used annually, and 2% of the total U.S. energy consumption in 1970.

SO WHY SHOULD A HIGH SCHOOL STUDENT BE INTERESTED IN DECAYING MUCK?- For the simple reason that this is a very good possibility for future power. One cow produces over 11,000 pounds of manure per year. One pound of manure produces about 1 ft^3 of bio-gas. Add up all the cows, chickens, pigs, people, and other waste producers, add on the weight of all the left-over corn stalks, leaves, rose petals, and other vegetable waste, and you have billions of cubic feet of totally unused burnable gas that could be used to run stationary motors, cook food, and heat houses. For years, sanitation stations across the country have been burning bio-gas to fuel their own power plants. At this time the chemistry of bio-gas production is not entirely understood. However, enough is understood to make this gas a very good possible source of energy. The possibilities for future work in this field are primarily in development of a marketable unit designed for small scale operation and organizing produc-

tion on a community level.

POSSIBLE SKILLS INVOLVED

plumbing
waste management
familiarity with building materials
welding
refrigeration

TABLE 3
ANNUAL EXCREMENT PER 1000 LBS LIVE WEIGHT

Animal	Lbs Excr.	Solid (lbs)	Liquid (lbs)
horse	18,000	14,400	3,300
cow	27,000	19,00	8,000
pig	30,000	18,300	12,200
sheep	12,000	8,300	4,200
hen	8,500	----	----

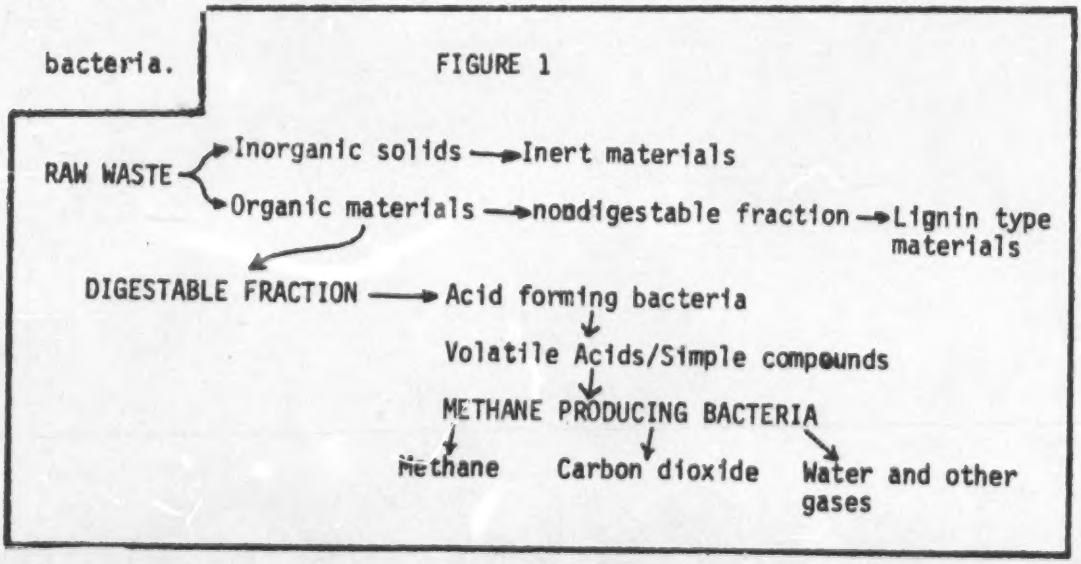
One cow per year produces enough waste to make 11,250 cu ft gas.

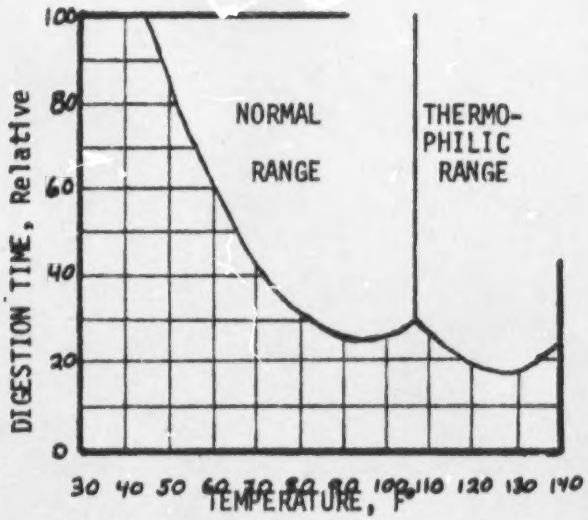
BIO-GAS PRODUCTION

RESOURCES: Animal waste, garbage, leaves from trees and harvested crops, and any other form of organic material that is subject to decay are all suitable materials from which to produce bio-gas. Chicken manure seems to work best, but it takes 150 chickens to produce the same amount as one cow. Human waste works well as long as it is not suspended in too much water from flushing toilets.

TEMPERATURE: Anaerobic breakdown of organic matter happens in two stages. The first is the consumption of the material by acid producing bacteria. The second stage is the consumption of these acids by methane producing bacteria.

FIGURE 1





In order to encourage this process, specific environmental conditions must be maintained. Temperature is of extreme importance. The optimum temperature for these bacteria is between 90 and 100°F. Bacterial activity, and thus methane production, decrease rapidly as the temperature drops. At 50°F there is practically no activity at all. The bacteria die at 118°F, so temperature must be carefully controlled.

ATMOSPHERE: It is equally important that the digestor be devoid of oxygen at all times.

CARBON/NITROGEN RATIO: Digesting bacteria consume carbon and nitrogen at a ratio of about 30:1. As a result, it is necessary to provide that balance of materials in order to promote the most efficient possible gas production. Chicken manure is very high in nitrogen. Stable wastes from cows and pigs would also be high because they are mixed with urine. Garbage, on the other hand, tends to be much higher in carbon and lower in nitrogen. Therefore, proper operation consists of feeding the digestor a combination of wastes that closely realizes a ratio of 30:1.

TABLE 4
CARBON/NITROGEN RATIOS OF SOME COMMON MATERIALS

S	
sawdust	.511:1
straw	.120:1
garbage	25:1
fresh weeds	20:1
manure	14:1

THE WAIT: When a digestor is started up, time is required for the bacteria to really begin producing. Under ideal conditions (95°F, with a 30:1 carbon: nitrogen ratio and a Ph of 8) it will take a digestor 40 days to produce 95% of the available methane.

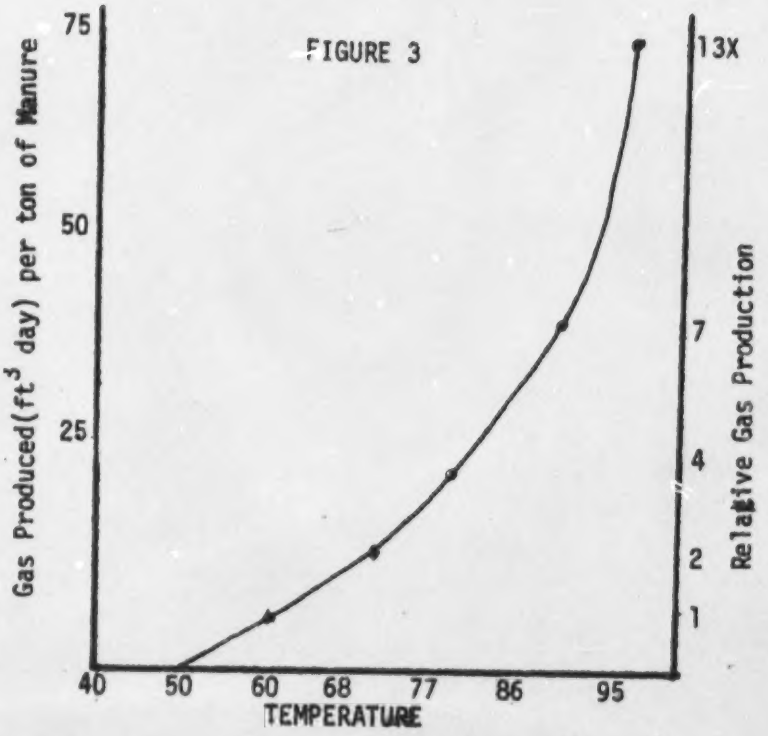


FIGURE 3

THE END PRODUCT: As seen in fig. 4, this process leaves several end products: Not only methane gas, but also a highly nutritious fertilizer. Figure 5 represents a typical, low yield bio-gas digestor.

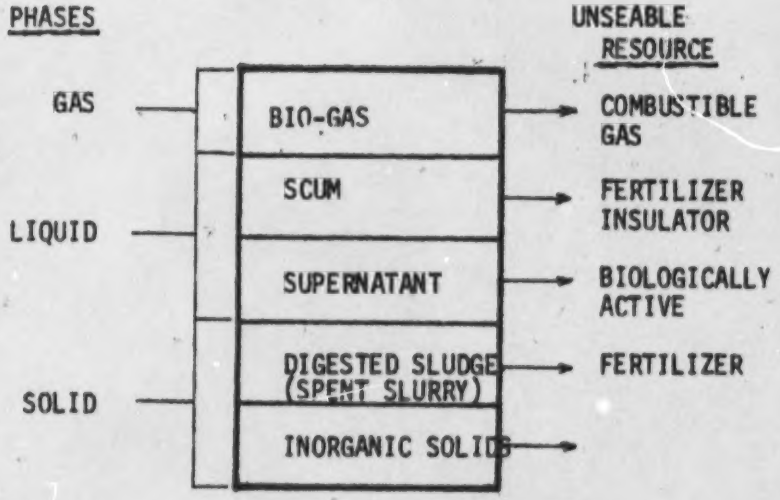


FIGURE 4

A unit is made of fifty-five gallon drums and bicycle tubes. A single batch in this digestor can produce up to 500 ft^3 of bio-gas. A family of five uses about 2250 ft^3 of bio-gas per month for cooking alone. That means that this system individually would not be enough for this family to cook with. They would have to produce almost three batches per month. Each batch would last about a week and a half, so three such systems would have to be in operation at the same time with starting dates staggered to meet this need. Of course a larger, more costly system may be more appropriate. At this time, all systems in use in this country are of the home built variety. People interested in producing bio-gas in quantity should investigate the subject in great detail. Refer to the annotated bibliography for further sources of information.

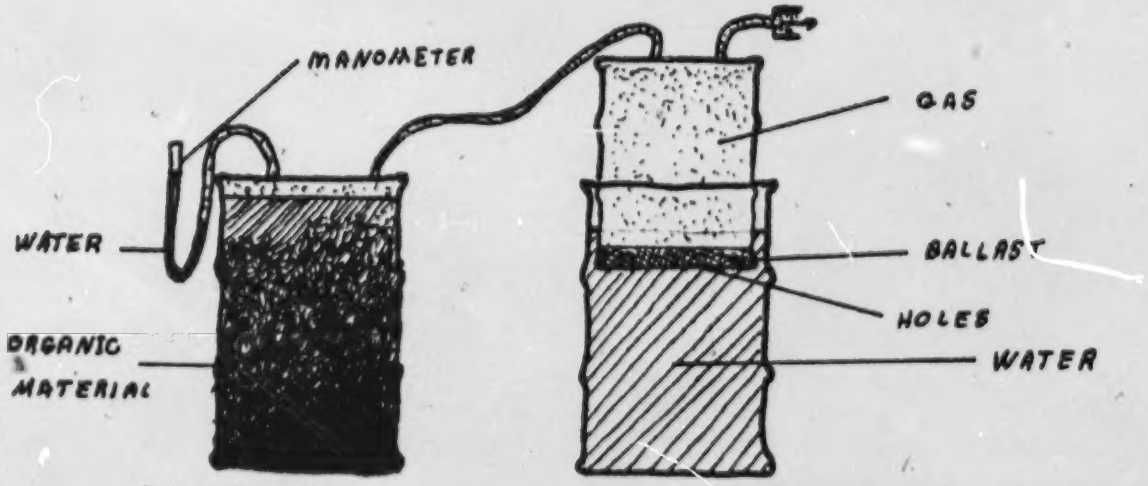


FIGURE 5

ANNOTATED BIBLIOGRAPHY

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Handbook of Homemade Power, 1974, Mother Earth News, Available from the Maine Audubon Gift Shop for $2.25. Good introduction to methane. Written in simple language with a practical approach.

Methane Digesters for Fuel, Gas, and Fertilizer, 1973, L. John Fry, New Alchemy Institute Newsletter #3. Available from New Alchemy Institute, Box 432, Woods Hole, Mass. 02543, $3.00 A must for further investigation. Good practical approaches and technical suggestions. Highly recommended.

Other Homes and Garbage, 1975, Leckie, Master, Whitehouse, Young, Sierra Club Books, Available from Audubon Gift Shop for $9.95. An excellant, in depth approach to home methane production. Highly recommended.

ACTIVITY A

A MINI-DIGESTOR

Materials cost: Less than ten dollars

Materials: 1 Gallon glass jug
Heavy plastic bag for gas holder
rubber tubing
2 tubing clamps
1 two-hole stopper for the glass gallon jug
glass tubing

This mini-system has four components: The manometer, digestion bottle, gas storage container, and the tubing.

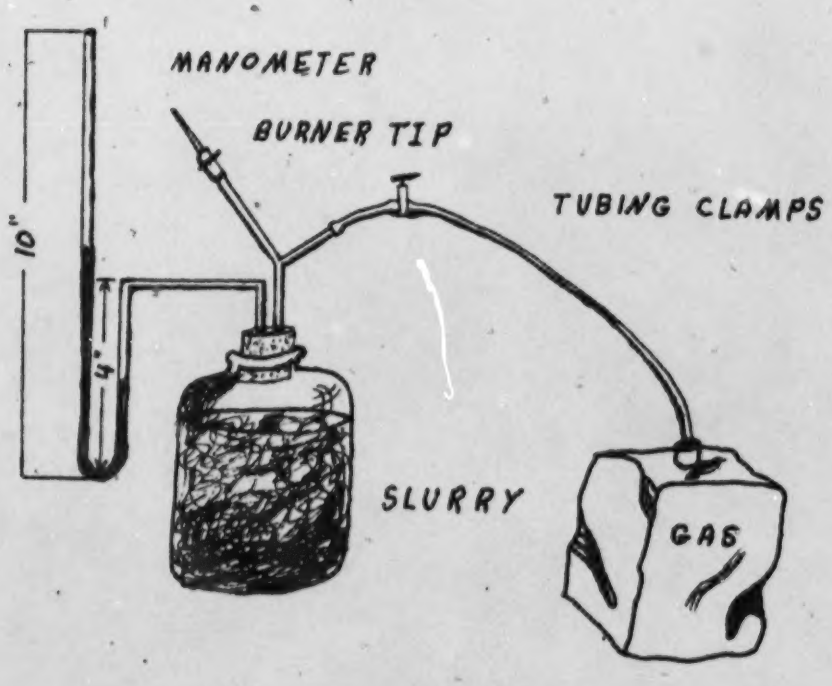
THE MANOMETER: This is a glass tube, bent to a U shape and partly filled with water. This will give the experimenter an indication of how much gas is in the system. Shown in the drawing, the manometer will indicate the inches of pressure in the system. It is important not to exceed the dimensions in the drawing as this is more than enough pressure to give you a burnable jet of gas, and will insure that you don't over pressurize the system. When too much gas is produced the water will squirt out of the top of the manometer.

THE BURNER TIP: Take a piece of glass tubing and draw it out as far as you can. This will give you a small enough jet to insure against back burning. Hook up the tubing and jugs as in the drawing.

THE SLURRY: Mix up some manure of any sort (chicken is best) with water. Add only enough water to make the final mixture the consistency of heavy cream. Pour the slurry into the glass jug leaving 3 to 5 inches of air at the top. Cork the bottle. Before connecting the gas bag, roll it up to remove excess oxygen. Ideally, the slurry should be kept at between 90 and 100°F. This can be accomplished by placing the jug near a radiator (not a stove!)

leave all valves closed at first. After a few days, the manometer should begin to register increasing pressure. At first, only carbon dioxide, which will not burn, will be produced, so let it out of the system. Test this by holding a match to the jet as you let it out.

If your carbon to nitrogen ratio is approximately 30:1, you will start generating methane within two weeks. If the mixture is off the bacteria will need extra time to balance everything out, so be patient. Once methane production begins, it will continue for at least a month.



ACTIVITY B

DESIGN A FARM BIO-GAS SYSTEM

You are a chicken farmer outside of Belfast, Maine. You are the proud owner of 20,000 chickens and have decided to convert all that manure into bio-gas.

You figure you can use the gas for cooking, heating, and running your farm machinery, but you have to estimate how much gas you will get and how much work you can obtain from the gas.

Using the references listed in the bibliography below, research an appropriate system. Design on paper the system you decide upon, or even better, build a model of it. This project will require a full terms work, so may be suitable as a final project.

Suggestions: Decide what your demand will be by estimating the present demand for your farm for fuel oil, gasoline, and cooking gas.

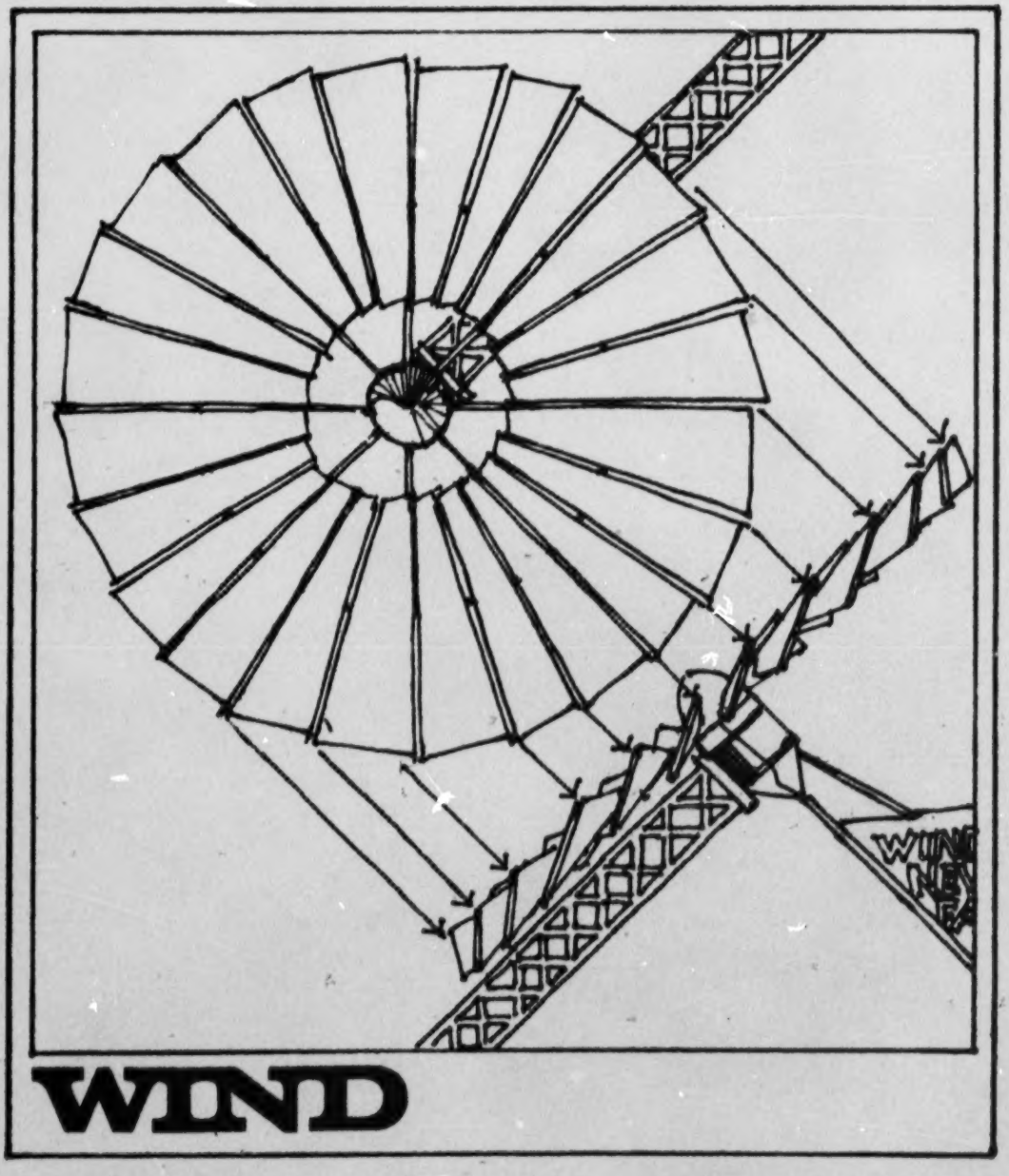
Write to the listed sources immediately as research is the first step.

SOURCES OF INFORMATION:

Methane Digestors, New Alchemy Institute Newsletter #3, Box 432 Woods Hole, Mass. 02543 A must for this project. It will cost you $3, but it may be all you will need.

EPA Methane Digestor State of the Art Report, write to: Tom Abeles, OASIS 2000, Box 1, Admin Bldg., University Drive, Rice Lake, WI 54868. This is a periodical started in November '76. You will be placed on their mailing list.

Byron McDonald's Methane Digestor, April '76 "Popular Science Magazine" or write to Byron A. McDonald, R.R. 2, Box 49, Vergennes, VT., 05491


WIND

INTRODUCTION

On the morning of March 26, 1945, research and development of wind powered electric generators came to a virtual stand still. On that day, in Rutland, Vermont the most ambitious and costly wind experiment to date came to a sudden and dramatic halt. On Grandpa's Knob, in Rutland, boasting two 65 foot stainless steel blades, stood a wind mill towering 110 feet above the brow of the hill. It was producing 1,250 Kilowatts of electricity which fed into Vermont's utility lines. Early in the morning of that day, a spar to one of the blades snapped and the blade was hurled 750 feet away. As a result, the project was scrapped, the mill dismantled, and the most important research in the field came to an end.

In recent years, the rising cost of fuel oil has rekindled interest in the wind as a source of energy. The prospect of a large market has sparked research for more efficient, less expensive wind turbine and pumping units. Wind energy has become a field of ever increasing opportunity for people with a variety of technical skills.

VOCATIONAL AREAS:	Directly related to wind generation are:
MECHANICS:	Gearing and gearing systems Tooling and metal fabrication Pumping and plumbing
ELECTRONICS:	AC/DC wiring systems Generator/alternator use and maintainance General home wiring
MATERIALS:	Metal, wood, fiberglass, concrete and others
DESIGN:	The design process as a research tool
AERODYNAMICS:	Air foils and energy conversion systems

THE BASIC WIND MACHINE

Power from the wind has been used for thousands of years. It was first used to pump water and, more recently to generate electricity. The two most common types in use today are the multi-bladed water pump, seen dotting many a mid-western land scape, and the two to four bladed, high speed electric generators once common in remote areas before rural electrification. Two specific systems are described below.

THE MAINE AUDUBON WIND PUMP

This system employs a multi-bladed fan which gives it high starting torque in low winds, but relatively low maximum rpm. The energy is mechanically transferred to a conventional deep well piston pump located at the botton of the mill tower which is geared 1:1 with the rotation of the drive shaft. The water is pumped directly into a four hundred gallon holding tank which will hold enough water to supply household needs when the wind is not blowing. The Audubon mill is a simple, yet expensive system (about 3,000 dollars, including drilling and lining the well). Analysis of the Audubon system presents the designer with numerous cost cutting possibilities.

An alternative to this rather expensive mill would be the Savonius rotor. This mill can be fabricated by someone with some skill in mechanics, and a little money. (See project A)

THE MAINE AUDUBON WIND PUMP

BAKER 8' WATER MILL

Gear box. All works in oil
ulti-blade prop creates gh torque, low max rmp
wind vane controls direction of propeller
ower made of three telephone oles
eciprocating rod to pump
ump

Figure 1

A TYPICAL GENERATOR SYSTEM

This system has two basic components; 1.) the horizontal generating plant (the mill itself), and 2.) the storage system. Figure 2 shows the relationship of these units along with the backup system and the house connection.

THE MILL

The alternator is a 4 KW/DC unit. It is driven by a three blade, high speed propeller. The basic components of the drive unit are:

AIR FOILS - Specificaly designed propeller blades.

GOVERNOR - A mechanism to keep blade rpm within safe limits in high winds

WIND VANE - To keep propellers facing the wind.

REGULATOR - Controls alternator output by regulating field charge.

DRIVE SHAFT AND BEARINGS

STEP UP - This set of gears will transform the 250 rpm of the drive shaft to 1250 rpm at the altermator, a ratio of 5:1. Generally, the alternator is on top of the tower with the rotor so that only wires run down the tower.

THE STORAGE SYSTEM - There are several methods of storing electricity. The most obvious, and popular, is storage batteries. This system employs a bank of lead-acid batteries. It is made up of three banks. Each bank operates at 120 volts DC and is capable of storing up to 12,375 amp hours. When all three are fully charged, they provide 10 days to three weeks power for a family of five, depending on such variables as night time lighting requirements. All large appliances must run on DC because the alternator and batteries both provide DC. AC is obtained through an INVERTER. This system employs a relatively economical in-line inverter, that can be plugged into a DC outlet to power a TV or similar small device. Heavy duty inverters designed to handle house loads are available, but they waste 25 to 50 percent of the power in converting DC to AC.

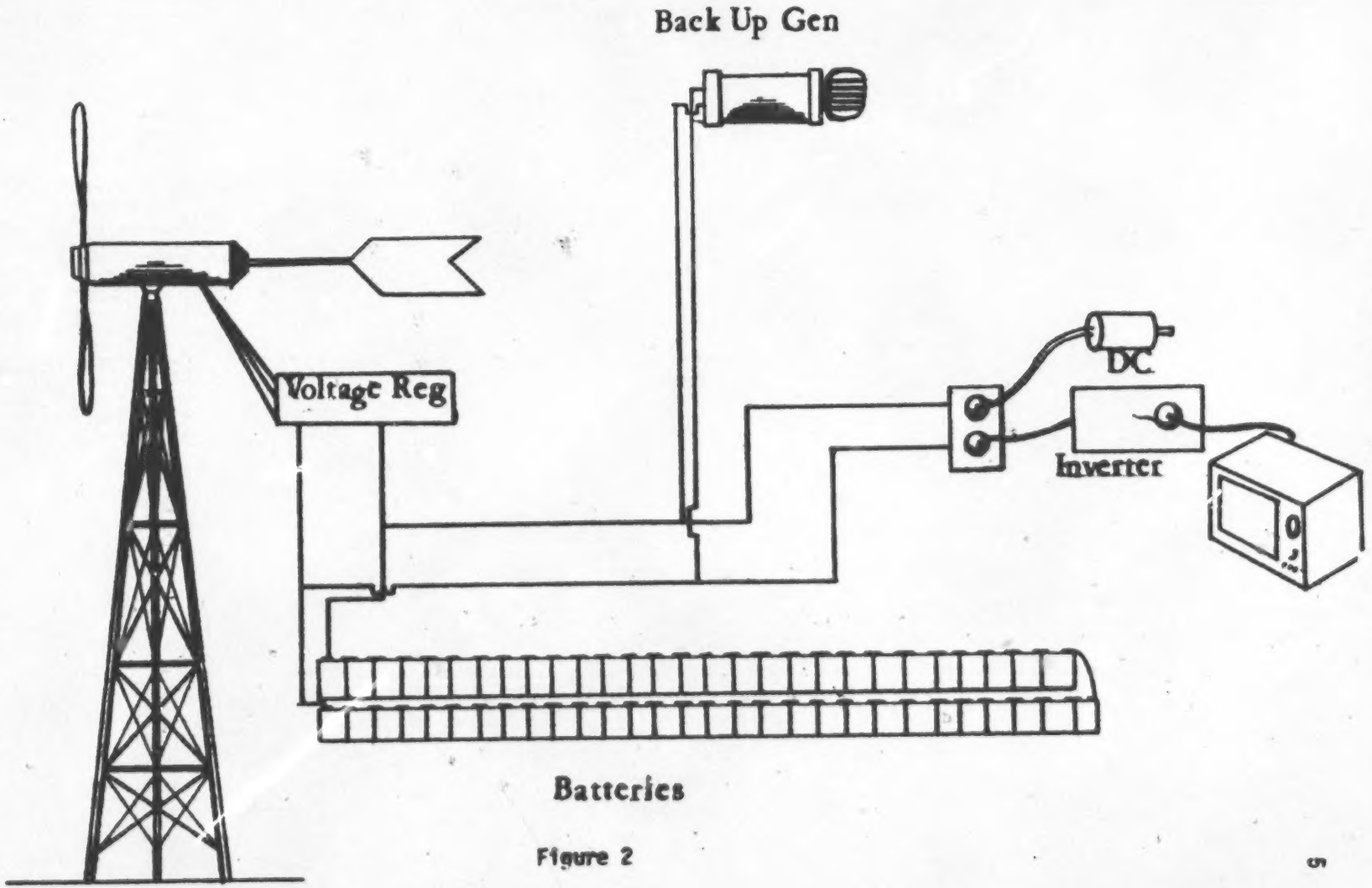


Figure 2

DESIGN PARAMETERS AND PROBLEMS

Theoretically, a wind machine can harness up to 59%, (.59) of the energy in the wind. In actual fact, machines have been far less efficient. A power coefficient of 0.4 is considered good. The two systems described are merely two examples of how the various design problems have been dealt with in the past. This section deals with alternative approaches to the design challenges of a wind system.

MILL ORIENTATION - Two basic types of mill are currently in use; horizontal and vertical.

Each orientation has advantages and disadvantages.

HORIZONTAL	VERTICAL
Advantages	**Advantages**
Higher speed of rotation Reduced mechanical drag	Always facing into the wind Generator can be on the ground -Self Govorning, Simpler, Cheaper
Disadvantages	**Disadvantages**
Subject to more stress More expensive	Less efficient

Since wind is an unlimited source of power, the issue of efficiency becomes less important.

STEP-UP - Clearly, the less step-up a system has, the more efficient it is. In most cases, however, some step-up is necessary. Some things for the designer to consider are:

BELT DRIVE - The requirement to periodically replace slippery belts at the top of the tower is a drawback. Gear and chain drive systems must be protected from rust and corrosion.

STORAGE - There are four methods of storage in use or under development. See Figure 3.

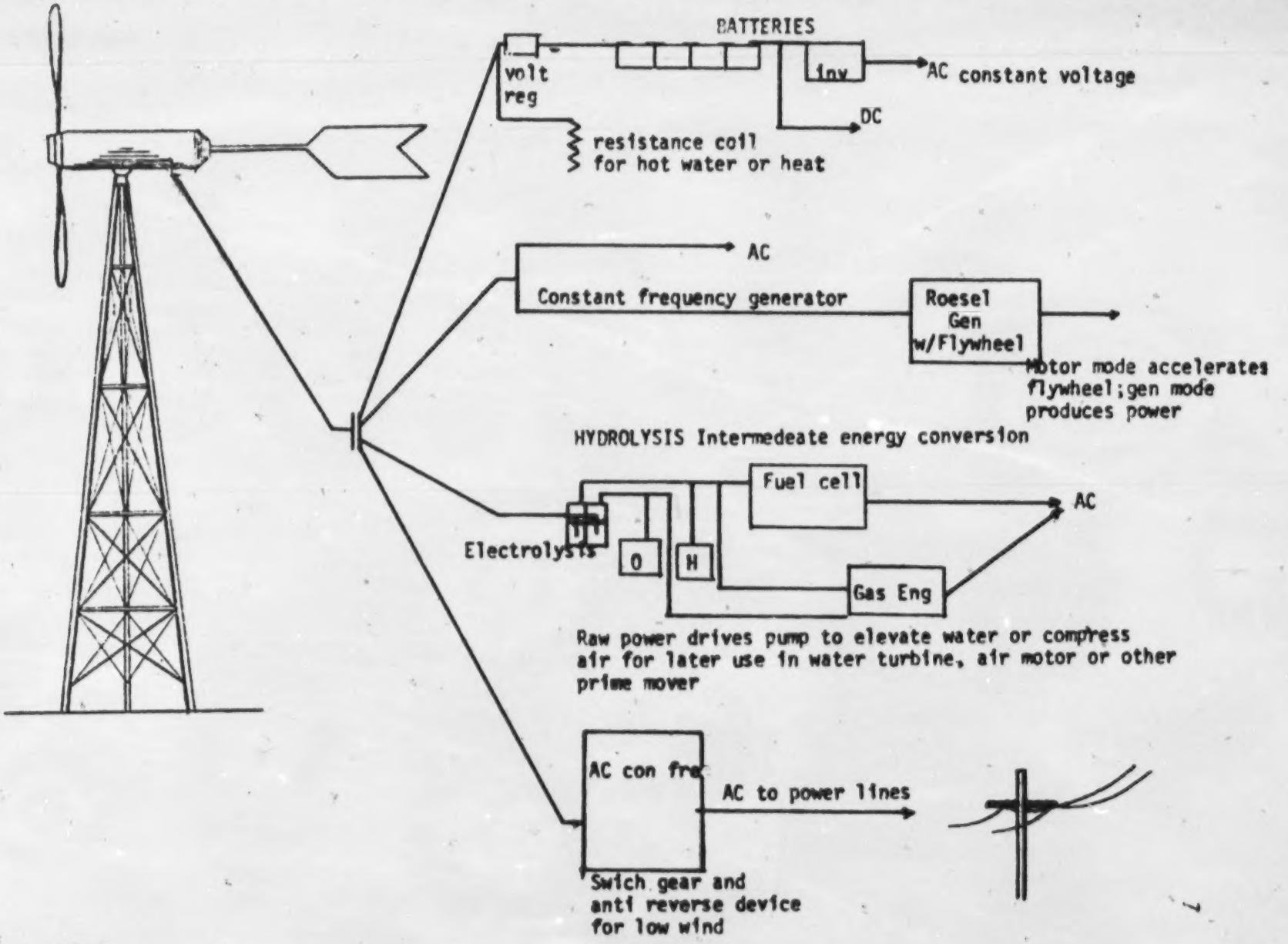

BATTERIES
volt reg
inv
AC constant voltage
DC
resistance coil for hot water or heat
AC
Constant frequency generator
Roesel Gen w/Flywheel
Motor mode accelerates flywheel; gen mode produces power
HYDROLYSIS Intermedeate energy conversion
Fuel cell
AC
Electrolysis
O
H
Gas Eng
Raw power drives pump to elevate water or compress air for later use in water turbine, air motor or other prime mover
AC con fre
AC to power lines
Swich gear and anti reverse device for low wind

Figure 3

COSTING

Generating electricity from the wind is EXPENSIVE. As of December 1976, a commercial 5 kW Mill cost $6,500. The additional costs of storage system and inverter amount to a sizable investment. Included in this packet is a list of manufacturers and distributors in the U.S. to whom you can write and get specific information.

CALCULATING POWER DEMAND

There are two major ways of determining electrical power needs. First, you can review past monthly power bills for the last year. Second, you can use a chart showing the average wattage of the most common appliances you use. By multiplying the wattage of each appliance used by the number of hours it is used in a month you can determine how much power you will need. Add up the total wattage, and you will have your monthly demand.

If you want to obtain all of your electricity from the wind, it will be necessary to reduce power needs as much as possible. The average American home uses anywhere from 300 to 900 kWh per month. A 2 or 3 kW wind generator with a 115 volt 150 AMP hour battery will supply only 120 to 200 kWh per month. You can reduce energy demand by eliminating wasteful useage, using only essential appliances. In his book, Electric Power From the Wind, Henry Clews goes into great detail about dealing with specific power needs. (see Annotated Bibliography)

A WIND DEMONSTRATION UNIT

It is possible that some sort of wind demonstration unit located at your school would be of great educational benefit to your students. A home power plant is an expensive proposition, but for demonstration purposes, it is possible to put together a generating system for far less.

WHY A WIND SYSTEM?

More and more, Americans are becoming aware of the increasing need to conserve fossil fuels. The world is running low on oil, and we still haven't planned the shift to other sources. The wind is one such source. As a means of demonstrating how electricity works, such a system would afford the teacher the opportunity to show all parts of a system in use, including the actual source of current. In addition, a wind mill on the roof of your building would be a novelty which would serve to perk up the imaginations of your students. It is possible that funding for such a project would be available from both state and federal sources involved in energy policy and research.

WHERE DO I FIND A SYSTEM?

The type of system employed in your school is dependant on funding available, and how you wish to integrate it into school activities. The most inexpensive possibility is the Savonius rotor described in activity A. This is a student built system that is very flexible in design and complexity. You may also want to buy and install a small commercial system. The major distributor of wind electric systems in the northeast is, Enertech Co., P.O. Box 420, Norwich, Vt. 05055. They have expressed an interest in developing a demonstration system with any school that contacts them. Ask for Henry Clews. Another possibility is to develop your system using a Jacobs wind charger. These vintage wind machines are no longer in production, but were very popular before rural electrification. They can be found in barns and junk heaps in many rural areas. Included in the bibliography is a book on refurbishing these machines. A good project and a good money saver.

annotated bibliography

BOOKS AND PAMPHLETS

Design with Wind, Douglas R. Coomley, 1974, Total Environmental Action, Church Hill, Harrisville, N.H. 03450

A good introduction into design considerations for a complete wind system; including sight design and mill type comparisons.

Electric Power from the Wind, H. Clews, 1973, Enertech Co. Norwich Vt.
An excellent guide to the homeowner or interested person to understand what it takes to install a home generating system. Highly reccommended.
Available at the Maine Audubon Gift Shop for $2.00.
Energy Book #1, Ed by Hohn Prenis, Running Press, 38 S. Nineteenth St. Phil. PA. 19103
General information on wind, as well as other sources of energy.

Energy Primer, Portola Institure, 558 Santa Cruz Ave, Menlo Park, CA 94025
Technical information on wind and other sources of power.

The Homebuilt, Wind Generated Electricity Hankbook, Michael Hackleman, Earthmind, Saugus, CA 91350
This book describes in great detail how to refurbish that beat up Jacob's Wind Generator you found in your grandfather's barn.

Other Homes and Garbage, Leckie, Masters, Whitehouse, Young, 1975, Sierra Club Books, 530 Bush St. San Fransisco, CA Available at Audubon Gift Shop
An excellent alternative energy text. Well organized for text book use. Highly Reccommended.

Simplified Wind Power Systems for Experimenters, Jack Park, Helio- Publ, Box 4301, Sylmar, CA 91342
Highly technical explanation of wind mill design. Excellent for advanced study.
Wind-Catchers, Volta Torrey, 1976, The Stephen Green Press, Brattleboro, VT
A history of wind power and development. Available from the Maine Audubon Gift Shop.

Wind and Windspinners, David Hackleman and David House, Earthmind, Saugus, CA.
An in depth investigation into the possibilities for the Savonius Rotor. Specific design and building suggestions. Available at Audubon Gift Shop.

PERIODICALS
Wind Power Digest,54468 CR31 Briston, In. 46507
Current developments in wind power discussed.

BIBLIOGRAPHIES
Wind Energy Bibliography,Windworks, Box 329, Rt.3, Mukwonago, Wis. 53149

Wind Energy Utilization , Sponsored by NASA, NSF and ERDA, Technology Application Center, U. of New Mexico, Albuquerque, New Mexico 87131

Activity A

THE SAVONIUS ROTOR

Time needed: forty hours for three people

The Savonius Rotor is a good, cheap wind machine which can be built by one to five people. It can be built to varying degrees of sophistication and offers a good vehicle for wind experimentation. The following procedure describes the required steps for building the simplest possible Savonius. It can be geared for generation of electricity or pumping water. Included in this description are sections on possible procedures to do either water or electricity.

THE ROTOR

The rotor is made from a 55 gal. oil drum, bisected and mounted on two 48" diameter plywood end plates. The plywood should be at least ½". The barrel halves, or impellers are welded together on the top and bottom before mounting on the plywood. They are mounted to the wood with stove bolts through the top and bottom of the barrel which were left intact. A hole is cut through the top and bottom of the impeller assembly to allow passage of the drive shaft. IMPORTANT: Be sure to split the barrel as evenly as possible because the finished halves must be balanced to avoid destruction in high winds. Make sure the barrel is in good shape with a solid top and bottom before you start. (See Fig. 1)

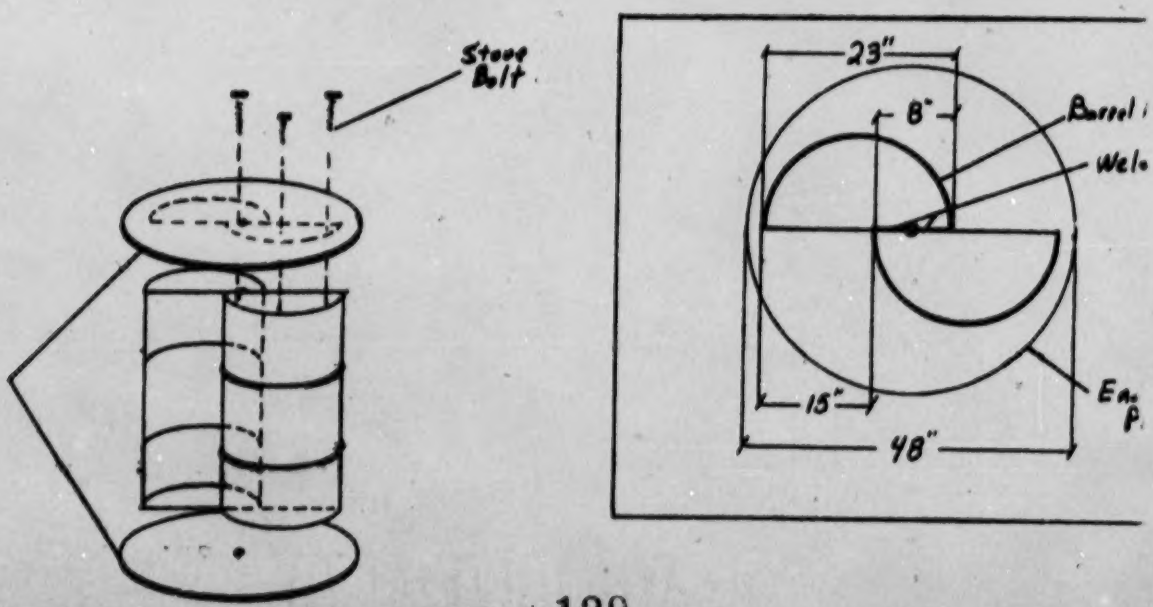


FIG. 1

THE DRIVE SHAFT

A 1 to 1½ inch pipe runs through the EXACT center of the assembly. It must extend 6" beyond each plywood plate to facilitate mounting of bearings and gearing mechanism. To secure the shaft to the end plates, two flanged collars should be used. They should fit snugly over the shaft. Those flanges should be stove bolted to the end plates and a 3/4" carraige bolt run through flange collar and shaft. (See Fig.2)

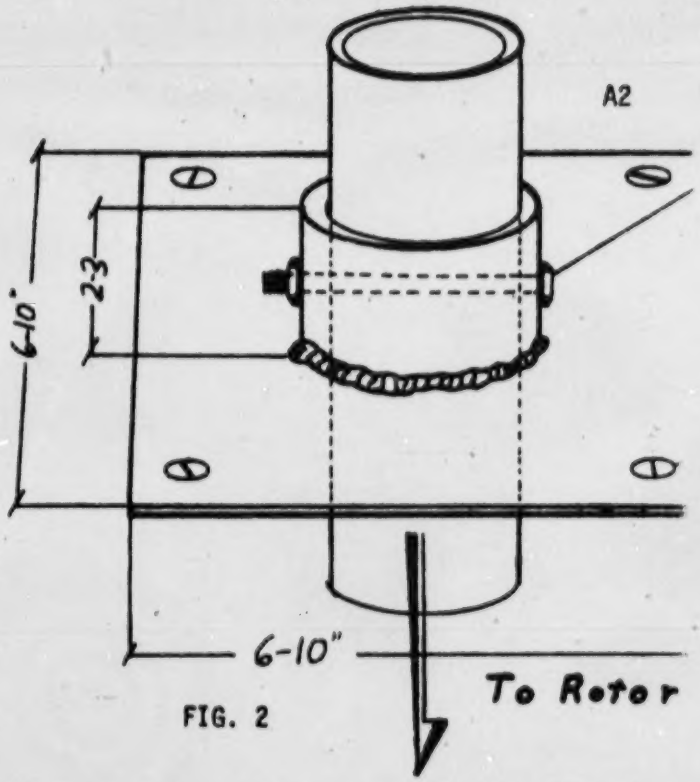


FIG. 2

BEARINGS

Top and bottom bearings should be flange mounted so they can be bolted to the frame. At least one, if not both of them, should be self-aligning. They should be weather proof, eccentric locking, and capable of handling axial as well as radial stress. They are mounted to the frame with stove bolts, (See Fig.3,4) and guyed with 1/8" cable. The bottom mount must allow the bearing shaft to pass through the frame to be linked to the pump/generator.

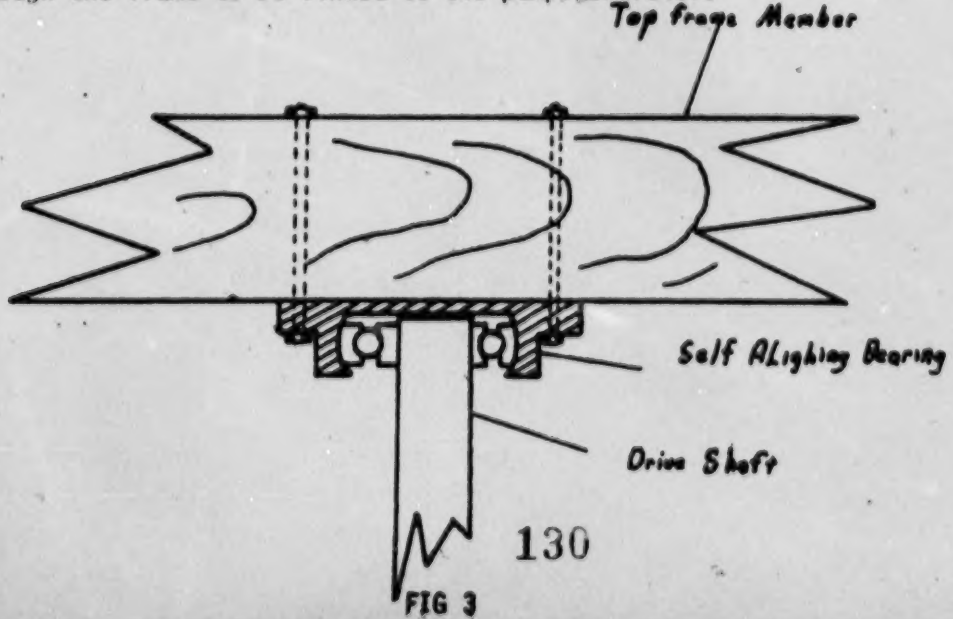


FIG 3

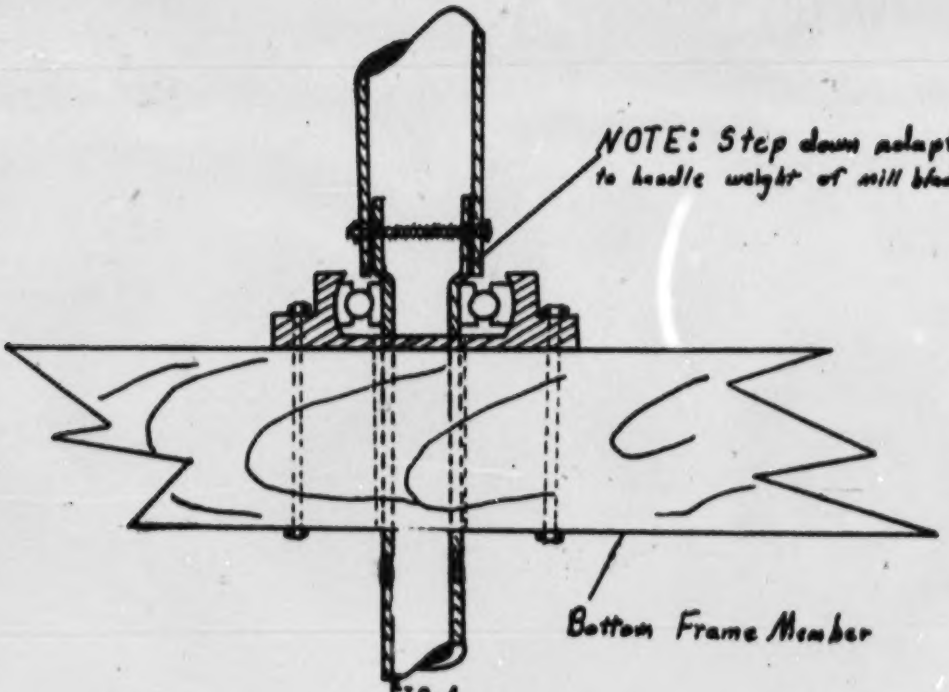


FIG 4

BALANCING THE ROTOR

To reiterate; an unbalanced rotor spells an early death for the mill due to excessive vibration. To balance the rotor place the assembled rotor horizontally on two level surfaces. Spin it. Spin it again. Does it always stop with the same point facing down? If so you must balance it. The two halves should be pretty close if you cut them carefully, so try running a short carraige bolt through the middle of the edge of the lighter rotor half. Spin it. Repeat the process until it is balanced. (See Fig. 5)

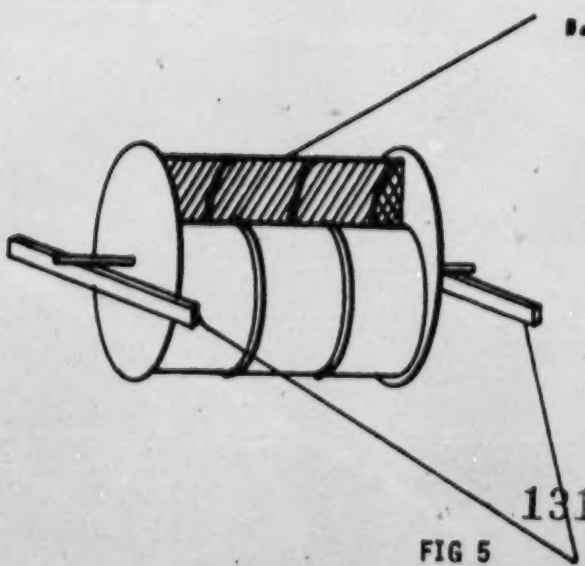
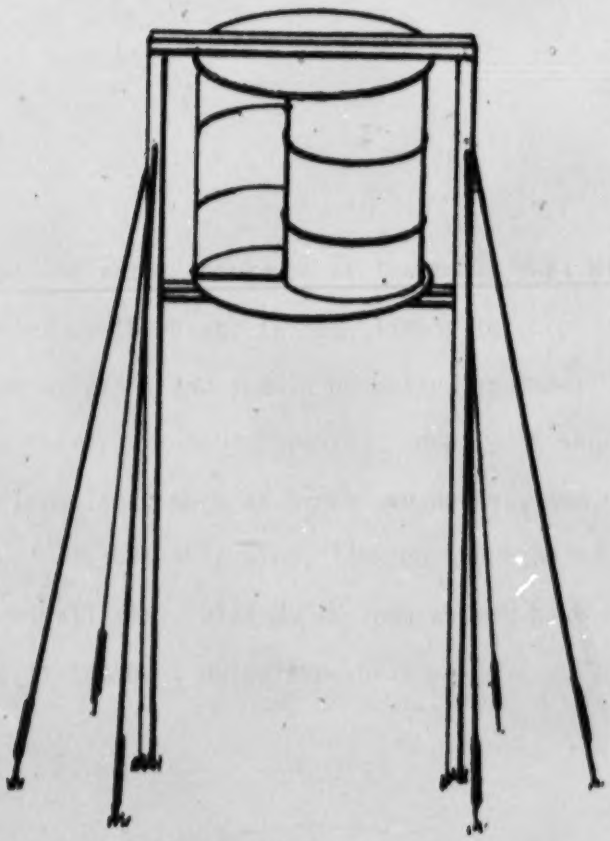


FIG 5

THE TOWER

The bottom of the rotor should be at least six feet off the ground. It will catch more wind up there and is less likely to chop someone in half. The frame is made of 2x4's and should be bolted together. (See Fig. 6) Placing the tower is fairly straight forward. Ideally it should be above any surrounding obstructions, such as trees and houses, and high enough to catch the maximum amount of available wind; like on the roof or the top of a hill. Even an unused football field will do as long as you have clearance in all directions. Common sense is the best guide however.



NOTE: Cables w/ Turnbuckle

FIG 6

PUMPING WATER

There are as many ways to link a pump to a Savonius as there are pumps. With this in mind, here are a few general guide lines you should know when deciding which pump to use and how to link it up.

TYPES OF PUMP

Decide how powerful you wish your pump to be. Link it up however you see fit and see if the rotor has the torque to turn it over. If you are using junk, an old washing machine pump should be workable. One of these can be linked in with a belt and pulley system. Again, how you mount the pump, and what size belts and pullies are used will depend on trial and error. The rotating shaft coming through the bottom of the frame can be fit for belts and chain drives. If you have a reciprocating pump, you will need reciprocating mechanical action from the mill. One possible solution is offered in figure 7.

If you are really ambitious, you can use the power from the mill to pump the water needed to operate a small solar collector such as the one in the Audubon packet on flat plate collectors. Together these systems would make a very satisfying and educational exhibit at your school on alternative energy.

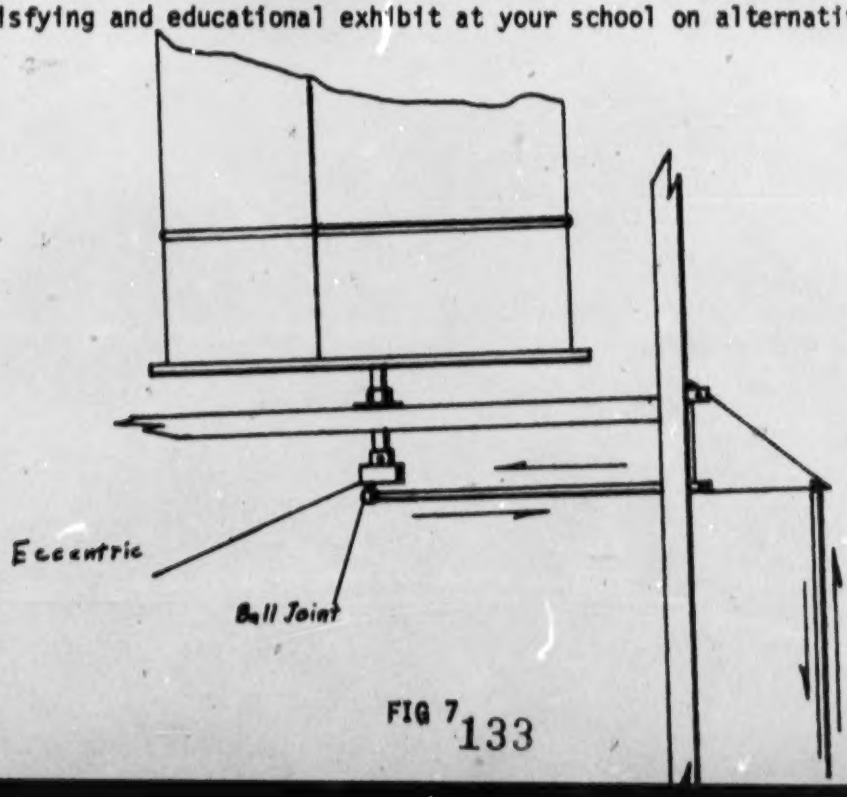


FIG 7

GENERATING ELECTRICITY

The three basic components (excluding the rotor assembly) of a generating system are: 1) the transmission, 2) the generator, and 3) the storage system. There are various ways to satisfy the demands of each of these systems.

TRANSMISSION

V Belts and Pullies These are usually the simplest systems, as automobile generators generally include V belt pullies. Pullies are readily available at the junk yard, and belts are easily available in all shapes and sizes. An automobile generator is designed to operate a fairly high rpm, so you will need to step up the transmission. With V belts this means putting a large pully on the drive shaft of the rotor, and a small pully on the generator. Depending on local conditions, you will have to put a 12-22" pulley on the shaft and a 2" pulley on the generator. Trial and error again.

CHAIN Drive A bicycle chain and gears can be used also. You will still need a step-up, and you will have to figure out a way to mount the gears on the rotor and generator, but it will relieve you of slipping belts. It is pretty noisy too.

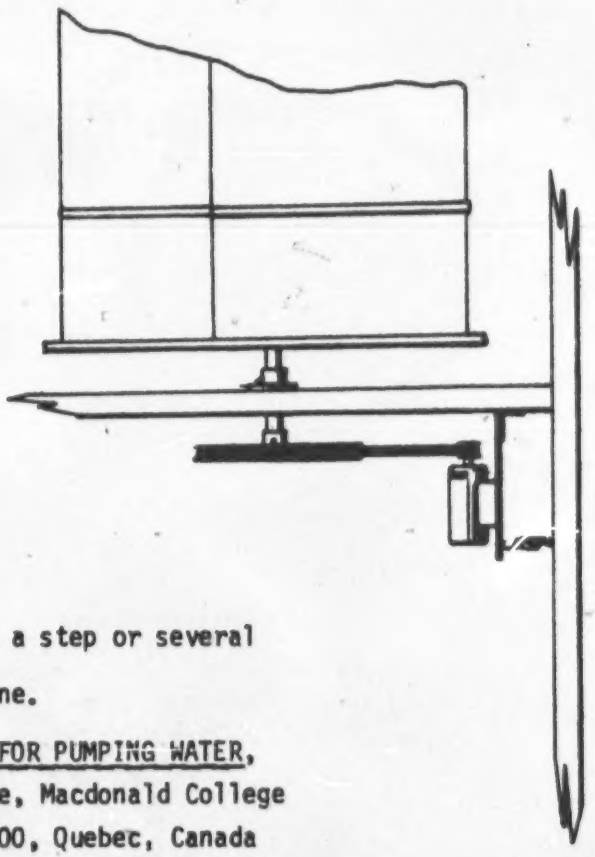
MOUNTING THE TRANSMISSION AND GENERATOR

The simplest solution is mounting the generator on the tower. Basic points to remember are to mount the generator far enough away from the rotor shaft to prevent excess belt slippage, and so that you can control belt tension. (See Fig.

STORAGE

Assuming that you have hooked up the generator and regulator correctly (just like in a car) you should be getting 6 or 12 volts DC. What are you going to do with it? You could run the wires to a light bulb that would light when the wind blew, or you could run it through a battery to store the power for use when the wind didn't blow. Find one or more batteries that have the same rating as the generat If you have just one battery, hook up the positive and negative terminals, and run lines from there to whatever you want to power. Obviously the more

batteries, the greater the storage capacity. If you can scrounge up two or more batteries, hook them up in PARALLEL. For more information on generator-battery systems, look through any good auto mechanics book. You will probably have specific questions about basic wiring. You can get answers from any basic home wiring text.



BIBLIOGRAPHY

These books will help is you wish to go a step or several steps further in designing a wind machine.

How to Construct A CHEAP WIND MACHINE FOR PUMPING WATER, 1965, A. BODEK, Brace Research Institute, Macdonald College of McGill Univ. Ste. Anne de Bellevue 800, Quebec, Canada HOA120, 95 cents

WIND AND WIND SPINNERS, 1974, Michael A Hackleman and David W House, EARTHMIND, Josel Saugus, CA. 91350, $7.50

WIRING SIMPLIFIED , 1975, H.P. Richter, Park Publishing, Inc. P.O. Box 8527 (Lake St. Sta.) Minneapolis, Minn. 55408, $1.39

SIMPLIFIED ELECTRICAL WIRING,sears & Roebuck and Co., 50 cents.

Activity B

THE STEP-UP (or REVENGE!!!)

Question: What is a step-up? How is it that a propeller turning at 200 rpm can turn a generator at 600 rpm?

Time needed: 1 class period

Materials needed: Two lengths of rope suitable for tug-o-war

One automobile wheel (without tire)

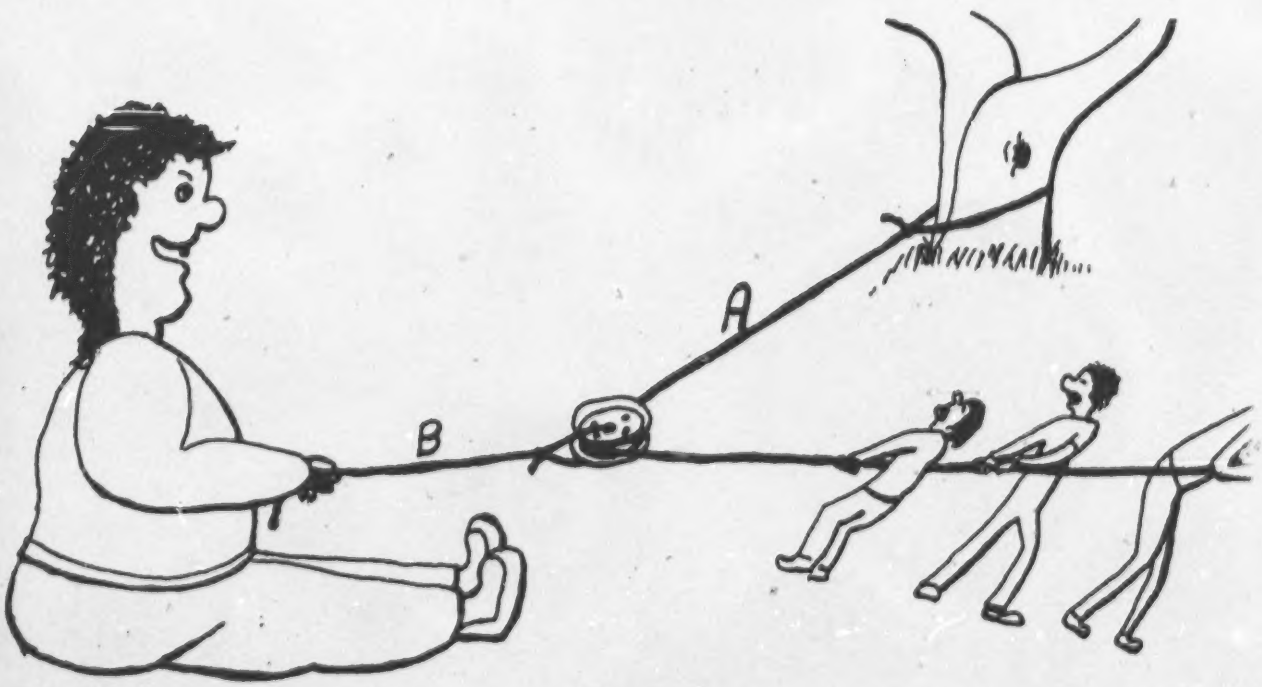
PROCEDURE:

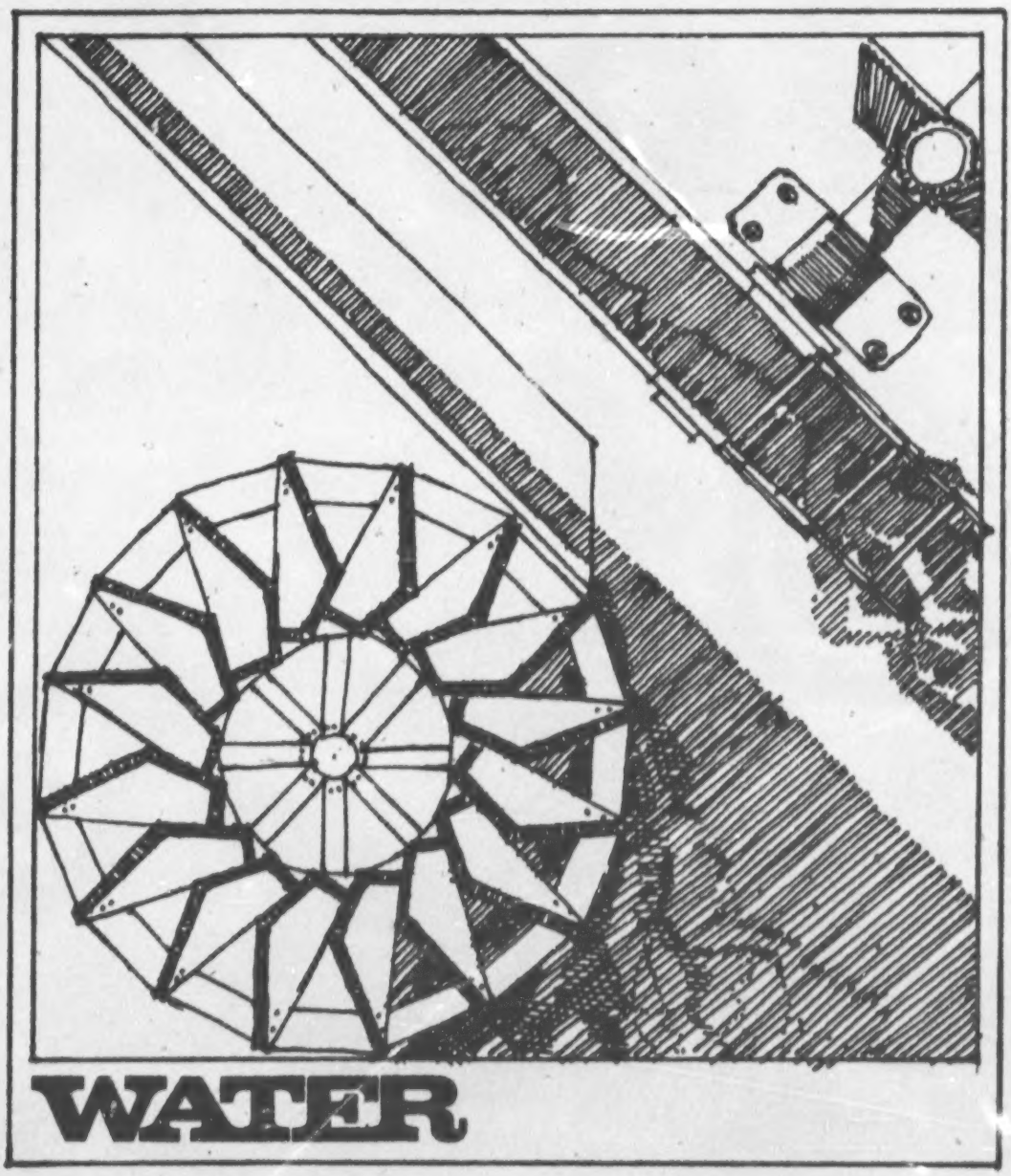
Step 1. Split up into teams and have a tug-o-war. Keeping in the same teams, try several times to establish which team has the heavies and which has the lightweights.

Step 2. Loop and tie both ropes per the drawing below.

Step 3. Now, the heavies latch onto line B and the lightweights grab the free end of line A. Take up tension and PULL!

Who won? Do you know why? What was the step-up ratio? How could you make a step-up with belts and pullies or gears?




WATER

WATER POWER

INTRODUCTION

From the time of Edison's breakthroughs until rural electrification in the 1930's, Americans have experimented with numerous ways of generating their own electric power. Wind power provided one source of electricity. Another source, water power lay virtually untapped, because, unlike the state of the art with wind generator systems, no machinery was readily available. Water generation of electricity remained in the background until the first major hydro-electric project was put into service. On this large scale, water power became an economical viable source of electricity.

This packet will not attempt to give an in-depth description of large projects. Small scale, owner-built systems are this packet's major concern. Given proper conditions (e.g. good water or some free equipment) such a small scale system is capable of freeing the home owner from the evermore expensive power bills, bad omens, that hang on refrigerators and peg boards across the country. Unfortunately there is not enough running water for generating power to satisfy all our needs. However that which is naturally available can be put to use, in environmentally sound ways, helping to lessen our dependence on limited fossil fuel supplies.

Figure 1 shows a typical, small scale water turbine. As each system must perform under a unique set of demands and topographical configurations, there is room for many variations on the one depicted. The elements common to all systems are indicated. Note the necessity of a dam which creates the HEAD to turn the generator. The water myst be controlled in this way for several reasons which will be explained on the following pages.

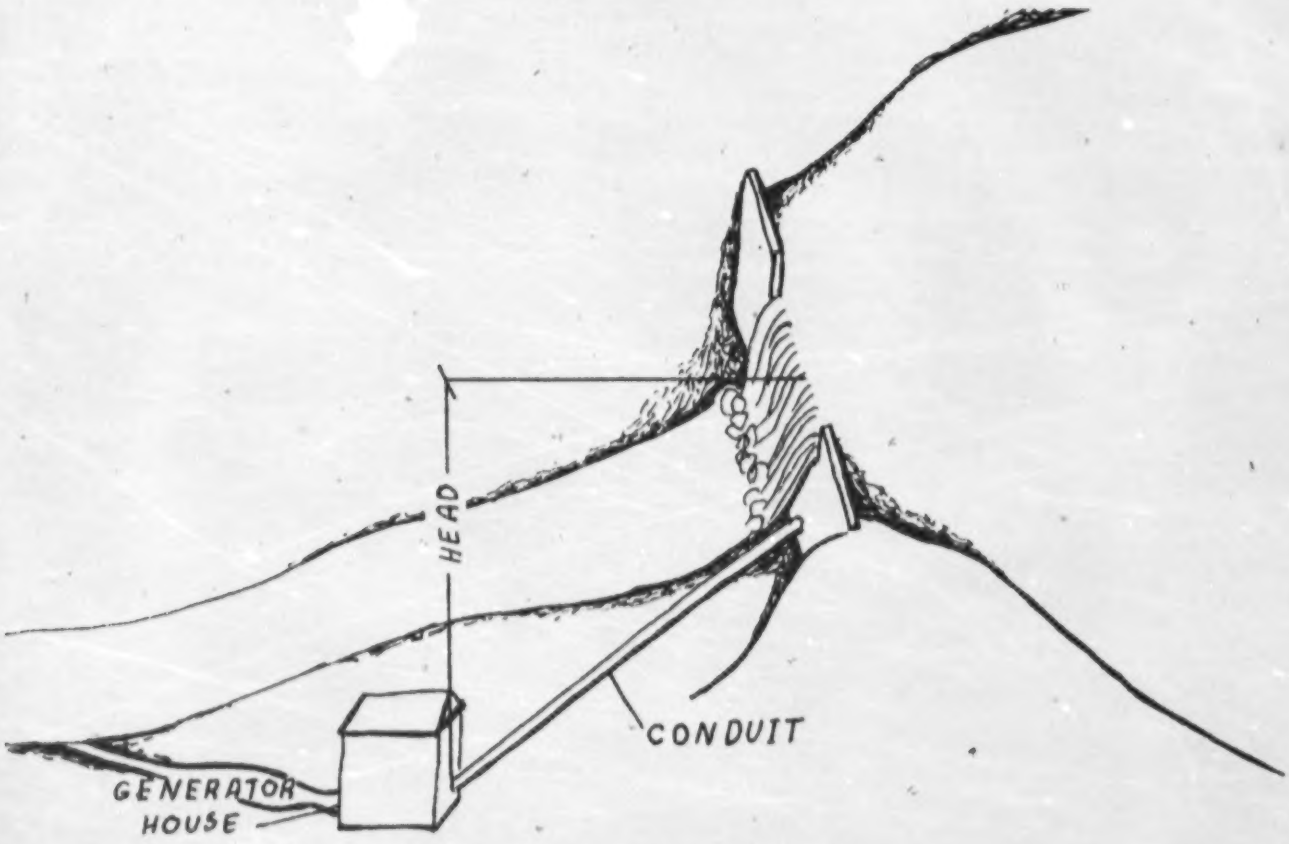


Figure 1

SKILLS INVOLVED

An ability to work with: Wood
Concrete
Other materials as designs demand

Plumbing
Electrical wiring
Power mechanics
Mechanical design
A little math and a lot of patience

THE POWER IN WATER

In any stream or river two kinds of energy are present. The velocity of flow determines the kinetic energy, and the stream's elevation (head) determines its potential energy. Rarely will a stream be found moving fast enough to contain a significant amount of kinetic energy. Most water mills and turbines are therefore designed to capture water's potential, or falling energy. This potential is a function of the vertical drop and the velocity of the flow. The basic formula for power is:

$$P = \frac{QHe}{11.8} = \frac{AVH}{11.8}$$

Where:

P is the power obtained in Kilowatts

Q is the flow of water in cubic feet per second

A is the average cross section of the stream in feet squared

V is the average velocity in feet per second (fps)

H is the height of the head in feet

11.8 is a constant which accounts for the density of water and the conversion from Ft-lb/sec to kW

e is the overall conversion efficiency. For most systems, e will be between .5 and .7.

EXAMPLE

You have a stream with a cross section of 1 square foot, a velocity of 1 ft/sec and a fall of 10 ft. With a conversion efficiency quotient of .6, how much electrical energy can you obtain?

Using the formula we find that:

$$P = \frac{AVHe}{11.8} = \frac{1 \times 1 \times 10 \times 0.6}{11.8}$$

$$= .51 \text{ kW} = 510 \text{ watts}$$

Assuming that these are average values for the flow of the stream, you will get

.55 kW x 24 hrs/day x 30 days/mo

= 396 kWh/month

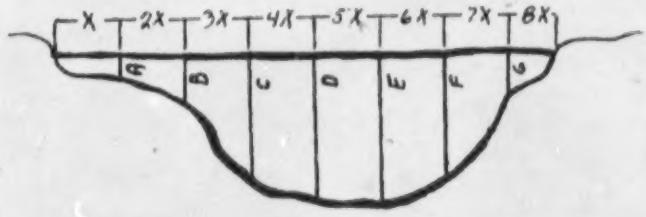
This is enough electricity to power all the lights, tools, and appliances - with the exception of resistance heating, electric hot water, and cooking - in the average home. These are average demands. Obviously, if you demand 1000 watts at once, you won't have enough electricity, so you have to have some way of storing power. In wind systems, electricity is usually stored in lead-acid batteries. In a hydroelectric system, a more direct and economical method would be to build the dam in such a way as to allow control over the amount of water going down the sluice way. Short term demands could then be met by temporarily increasing the flow rate.

It is important to know not only the average flow of the stream but also the yearly high and low flow rates in order not to be short in the summer or flooded out in the spring. The only way to obtain these figures is to measure the stream several times over the course of a year prior to building the dam.

DETERMINING FLOW, CROSS SECTION, VELOCITY, AND HEAD

As we saw in the equation, the power P was given as the product of the following four variables:

CROSS SECTION. At a given point in the stream, run a line, real or imaginary, perpendicular to the flow. As shown in Figure 2, measure the depths at a suitable interval. Average the depth readings taken at this section and multiply by the width at the surface. Do this several times in different places and average the overall results to obtain a more accurate reading.



$$[A+B+C+D+E+F+G]8X = CS$$

Figure 2

VELOCITY. Measure off about 100 feet of stream that is regular and as straight as possible. Place a 3/4 submerged bottle into the upstream end of the hundred foot section. Time the bottle's passage. Divide the distance by the time to obtain the average velocity. In order to compensate for drag at the bottom and sides of the stream, multiply the result by 0.8.

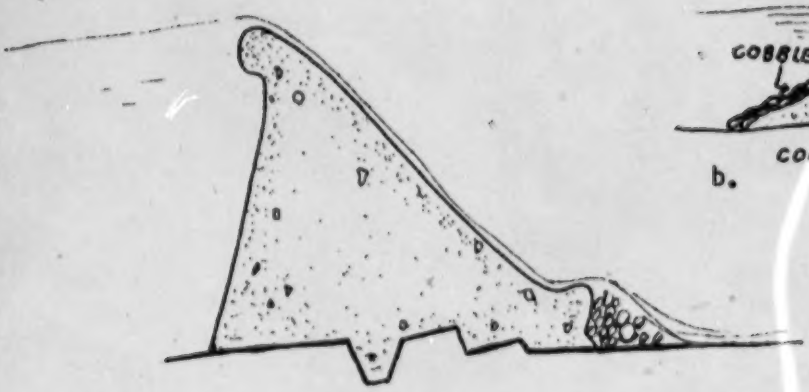
FLOW. As the equation suggests, the flow in cubic feet per minute is equal to the product of the cross section in sq. ft. times the velocity in feet per minute.

HEAD. The head of a stream section is the relative difference in height between the top and the bottom of the section. Ideally, the head should be achieved with the minimum dam height but the maximum drop. Practically, a minimum head of 10 feet is required. Usually, a dam is required to create a usable head. The reason for measuring upstream from the dam site is to get an idea of how large a pond the dam will create. If a seven foot dam would flood a ten square mile area behind it, it would be better to start thinking about where to put a wind mill.

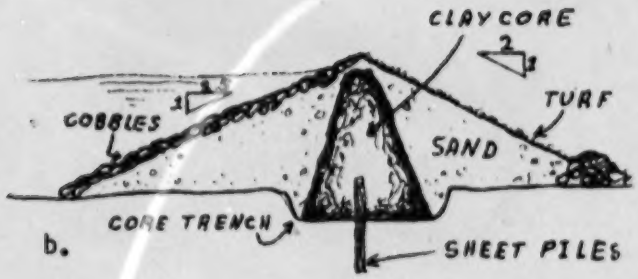
DAMS

Building a dam takes a fair amount of planning, and a lot of lugging. Figure 3 (a-f) shows sections of several different types of dams. If a dam of more than five feet in height is called for, one should have it designed by an engineer. For small electrical demands the dams shown will suffice. Included in the dam design will have to be a conduit, taking the form of a pipe for a turbine, or a notch and open runner for an old-fashioned water wheel. In both cases, the conduit will facilitate control of the flow over the dam. The dam should be located where the banks are high, and the stream is steep. The type of stream bottom will also determine the design. Dams have to resist great lateral forces, and must be able to handle high water in the spring. Water has a tendency to seep through the bottom of any dam. For this reason, unless the stream bed is clay, sheet piles must be driven into the bottom.

Figure 3

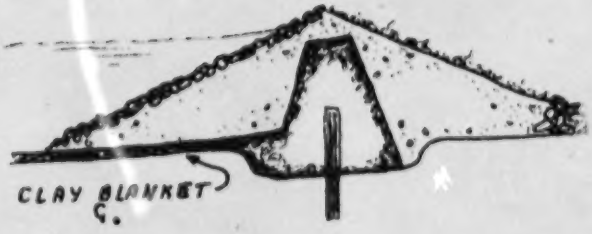


a. Concrete

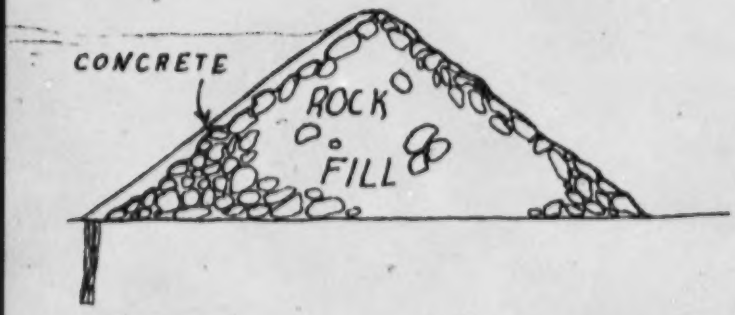


b.

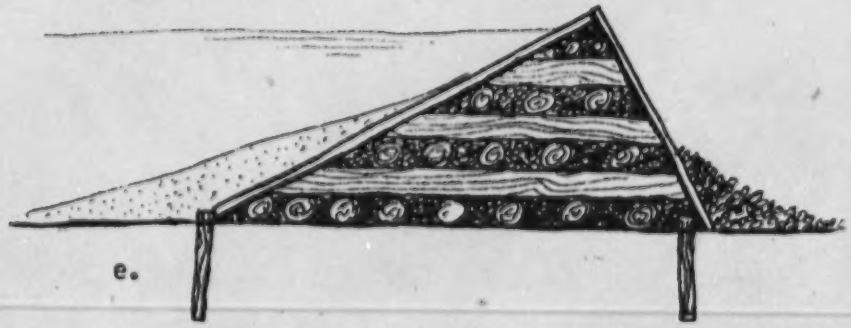
b and c. sand filled



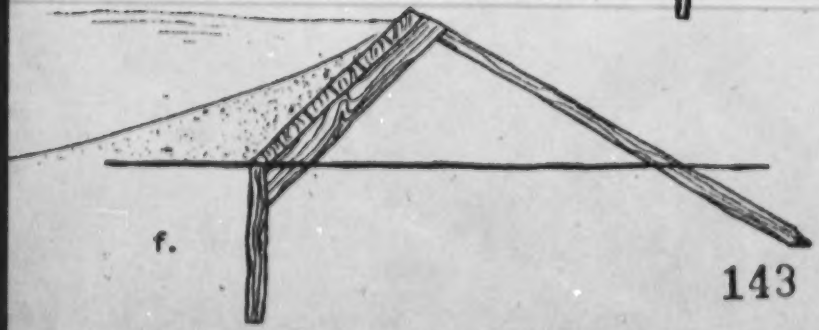
c.



d.



e.



f.

e and f. crib dams

Building a dam is no mean feat. Before starting such a project, it is reccommended that quite a bit of further investigation be done.

WHEELS AND TURBINES

The "old fashioned" water mill, still seen occasionally in the Northeast, is a slow speed, low technology affair. Its low speed (5 - 15 rpm) must be stepped up mechanically in order to run a 1000 rpm generator, but it is relatively simple to build and maintain. Higher speed turbines tend to be more expensive and much more complicated, In most cases, it is wise to purchase a manufactured unit.

Figure 4 depicts the three most common types of slow speed water mill. Of these three, the brest wheel is least recommended as it is the most difficult to set up and maintain. The overshot wheel, however, is a very good design. It can be used with a head of 5 - 15 feet, the diameter of the wheel being 3/4 of the head. Undershot wheels are better for low heads. They can be as much as twice the head in diameter.

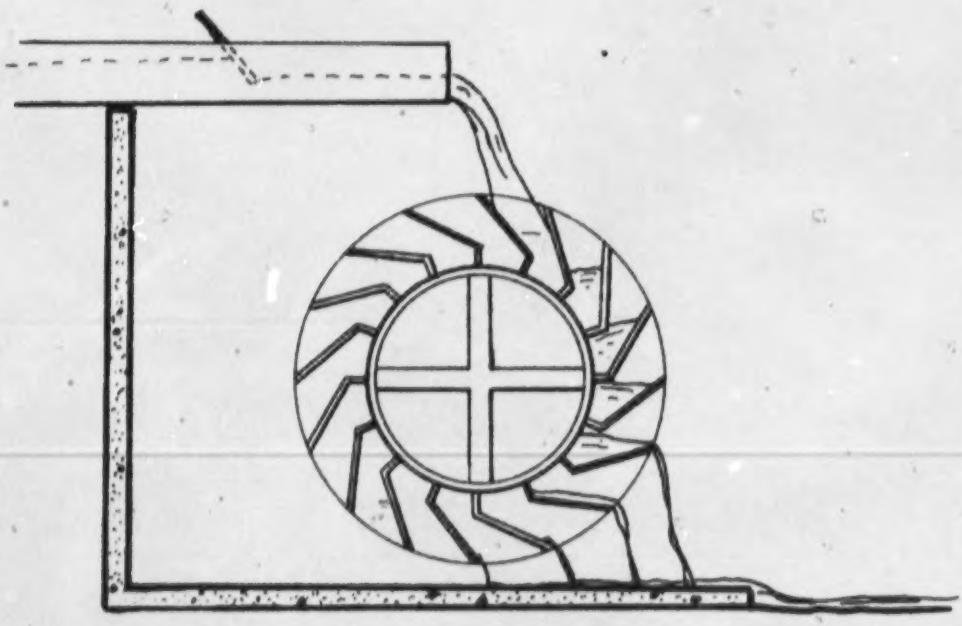
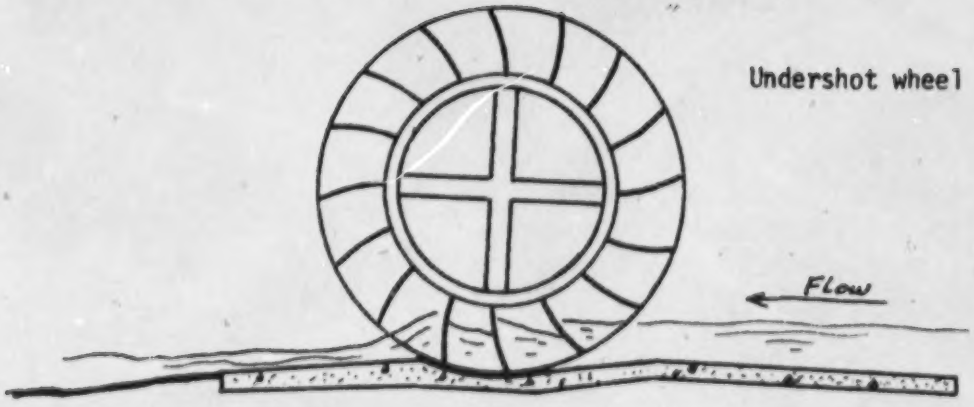


Figure 4. Overshot wheel.

Figure 4. Brest wheel



Turbines are high speed devices that run on water pressure rather than mere weight. Figure 5 shows the basic concept behind turbines. The largest manufacturer of water turbines in the U.S. is the James Leffel Company of Springfield, Ohio. More information on their units can be obtained by writing directly to them.

Water power may or may not be a viable, localized form of power for Maine. To date, too little research has been done to determine the full extent of the possibilities, but it is, with the right conditions, a very good source of both mechanical and electrical energy.

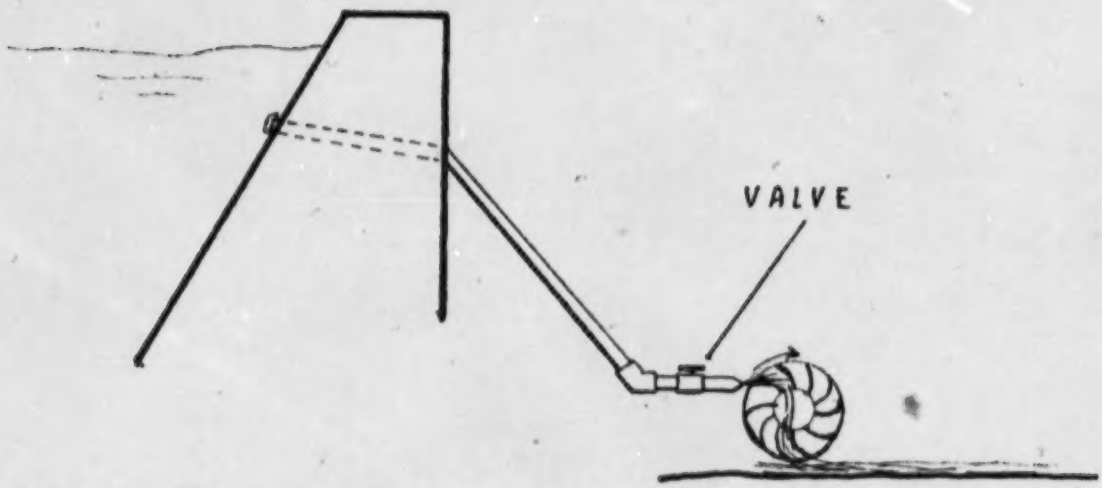


Figure 5

A water turbine.

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"Improved Vertical Samson Turbines", Bulletin 38. Springfield Ohio: James Leffel and Co. The above bulletin gives information on small turbines manufactured and available from: James Leffel and Co., Springfield, Ohio 45501

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Mockmore, C.A. and Merryfield, F. 1949. The Banki Water Turbine. Bulletin Series no. 25. Corvallis, Oregon: Oregon State College. This book describes a Banki turbine made by students of the university and analyzes the results of experiments performed with that turbine.

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WATER POWER

ACTIVITY A 2 Applications of Water Power

A large water wheel operates on the potential energy of water. The weight of the falling water causes the wheel to turn. A high speed turbine, however, operates on kinetic energy created by water flowing under pressure from the bottom of the dam.

Materials needed:

1 55 gallon drum

1 garden hose (attached to pressurized water system)

2 flush mount spigots

Time: 1 class

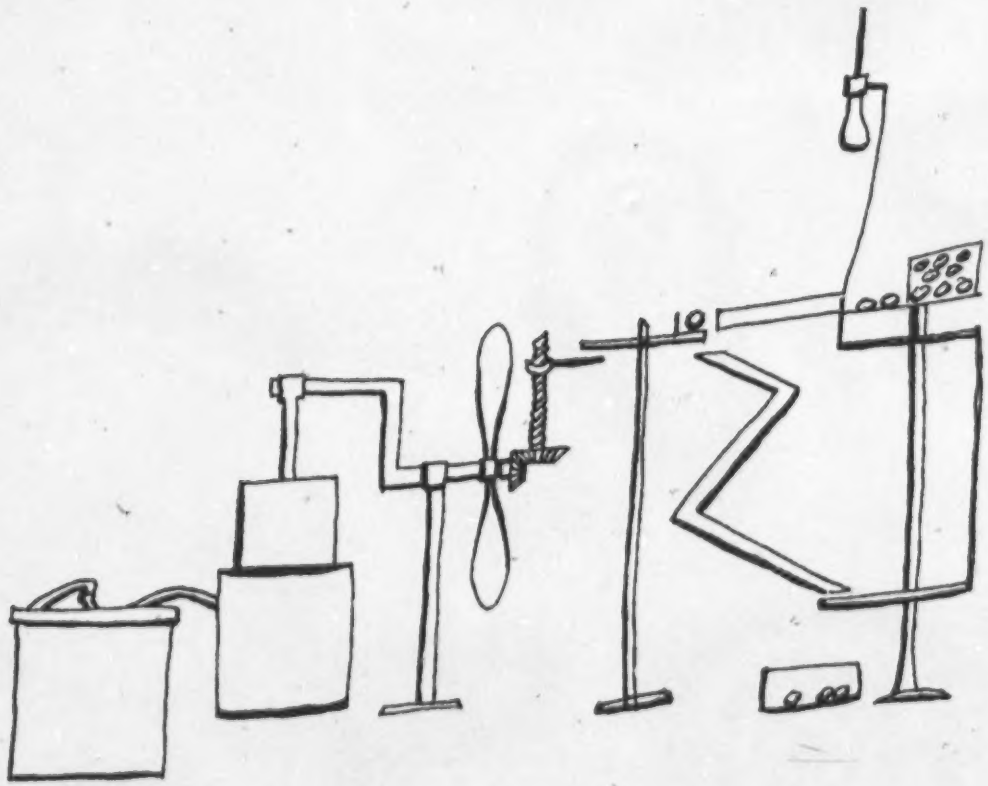
1. Set up barrel per the drawing
2. Fill the barrel with water and keep it running
3. Open the top and bottom valves equally until they are letting out as much water as is coming in so that level of water in barrel stays the same

What happens? Why? What is the difference between the water power coming out of the top spigot and the power coming out of the bottom one?

ACTIVITY B Build a Working Model of a Watermill

Using the tap as your source of water, design a strictly mechanical water mill. Design a water wheel that will utilize the running water, and hook the turning wheel into as many mechanical devices as you can dream up. Possibly you could use water to power a kind of mechanical sculpture.

The amount of time it takes is up to you, and the complexity of your creation, a matter of imagination.



ACTIVITY C Design a Small Scale Water System

Using the information given in the introduction, determine how much power you can extract from any local stream, within easy access.

Determine your Head and flood plain by using a transit. Imagine how you would build your generating station and decide what steps you would have to go through to make the resevoir as useful as possible. What kind of dam would you build? Where would you build it?

This is a project that should take several days to complete. For a final presentation, make a model of the completed system, or draw out plans including all the information you have taken in.